Grain storage techniques

Evolution and trends in developing countries

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109

GASGA

GROUP FOR ASSISTANCE ON SYSTEMS RELATING TO GRAIN AFTER HARVEST

Food and Agriculture Organization of the United Nations

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Edited by
D.L. Proctor
FAO Consultant

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FOREWORD

With an annual worldwide production estimated at more than two billion tons in 1992, grain crops provide the world's primary staple food. The FAO's Agricultural Engineering Service recognizes that dissemination of knowledge on appropriate grain storage facilities and techniques to its developing member nations remains very important. Therefore AGSE decided to update and revise the FAO Manual No. 60 "Handling and Storage of Food Grains" prepared by Mr. D.W. Hall in 1970, and which was subsequently reprinted three times.

The importance of grain storage as part of the marketing, distribution and food security system is well recognized. As early as 1971, the Group for Assistance on Systems relating to Grain After-harvest (GASGA), in which FAO participates, brought together experts and coordinated activities on research and development. In 1978, following the resolution of the UN General Assembly which called for the reduction of post-harvest losses, FAO launched the Special Action Programme for Prevention of Food Losses (PFL). Since then more than 250 projects have been implemented world wide under this programme.

During recent years, as a result of privatization and liberalization of trade, the organization and management of grain storage has changed in many developing countries. This restructuring of the grain storage sector has created a demand for information and knowledge from the emerging private entrepreneurs operating in the storage sector. In the previous storage and distribution systems, functions such as collection, storage, regulation of supplies, food security and price control, were often entrusted to parastatal marketing boards. Skills have been developed, facilities have been installed and methods taught to their staff, often at high cost. These skills have now to be acquired by the new "actors" of the privatized storage and distribution system. The purpose of the Bulletin is to contribute to the transfer of knowledge on grain storage to persons involved in the storage of grain. This joint production FAO-GASGA Bulletin is aimed at private and public sector storage operators, extension workers, students and researchers. However, the varied topics covered in the chapters are intended for persons each having different interests in the subject.

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CHAPTER 1

ECONOMICS OF GRAIN HANDLING AND STORAGE IN DEVELOPING COUNTRIES

THE ROLE OF STORAGE IN THE ECONOMY

In most countries grains are among the most important staple foods. However they are produced on a seasonal basis, and in many places there is only one harvest a year, which itself may be subject to failure. This means that in order to feed the world's population, most of the global production of maize, wheat, rice, sorghum and millet must be held in storage for periods varying from one month up to more than a year. Grain storage therefore occupies a vital place in the economies of developed and developing countries alike.

The market for food grains is characterized by fairly stable demand throughout the year, and widely fluctuating supply. Generally speaking people's consumption of basic foods such as grains does not vary greatly from one season to another or from year to year. The demand for grain is 'inelastic', which means that large changes in the market price lead to relatively small changes in the amount of grains which people purchase.

Market supply, on the other hand, depends on the harvest of grains which is concentrated within a few months of the year in any one area, and can fluctuate widely from one year to the next depending on climatic conditions. New varieties that have shorter growing periods, and variation in climatic conditions and farming systems in different regions of a country, can help to even out the fluctuations in market supply. But even in a country such as Indonesia, which has diverse climatic and farming conditions and where 90 per cent of rice land is under short duration high yielding varieties, about 60 per cent of production is harvested within a three month period (Ellis *et al.* 1992).

The main function of storage in the economy is to even out fluctuations in market supply, both from one season to the next and from one year to the next, by taking produce off the market in surplus seasons, and releasing it back onto the market in lean seasons. This in turn smooths out out fluctuations in market prices. The desire to stabilise prices of basic foods is one of the major reasons why governments try to influence the amount of storage occurring, and often undertake storage themselves.

COSTS AND INCENTIVES TO STORE

Both producers and consumers benefit from stable prices, which reduce the uncertainties associated with planning farm investment and household expenditure. However storage involves costs, and the only way in which these costs can be recuperated is through a **price spread**. If storage is to be profitable, people who store grain must receive a price on sale which at least covers the costs of storing the grain since harvest. These include:

- The cost of the store itself (often a rental cost);
- Labour and supervision;
- Pest control;
- Storage and spillage losses; and
- Cost of capital invested in the grain.

In practice, the costs of storage depend on the commodity stored, on the type of storage system, and on unpredictable and variable factors such as pest incidence and climatic conditions. Storage costs also depend on the circumstances of the person, the business or the institution who is storing. The most variable component of storage costs is the cost of capital. For a small farmer or trader, capital may be scarce and costly, and their only access to loans may be from money lenders charging rates of 10% or more per month. On the other hand a Government Marketing Board may have preferential access to loans at low interest, at rates of as low as 10% per annum. There is, therefore, no single cost of storage.

WHO STORES AND WHY?

Farmers, traders and governments all have reasons for storage other than the profitability of the storage enterprise itself. Storage is a component within a farming system, a trading enterprise, or a government policy, and may be undertaken because of its contribution to other activities or objectives within these broader contexts.

Farm Storage

For **small farmers** the main purpose in storing grains is to ensure household food supplies. Farm storage also provides a form of saving, to cover future cash need through sale, or for barter exchange or gift-giving. Grain is also stored for seed and as inputs into household enterprises such as beer brewing, or the preparation of cooked food. When there are significant inter-seasonal price variations, small farmers often store for speculative gain, that is to say they 'play the market'. This is most common in more prosperous areas, such as the Southern Highlands of Tanzania and southern Mali, which produce a mixture of cash and food crops, and where farmers' financial circumstance make it easier for them to sell when the price is best. Speculative considerations are even more important in the storage decisions of large-scale commercial farmers.

Despite the desire to store grain in order to cover food requirements and future cash needs, farmers often sell a large proportion of their produce at harvest, when prices are low. This is frequently the case with deficit producers, who must satisfy cash needs immediately after the harvest, only to buy in food later in the season.

There is an ongoing debate about whether farmers are forced to sell because of debt and economic dependence on others, or whether they sell because they regard storage as too costly (in terms of time), or too risky (given the risk of losses and unpredictability of future prices), or unprofitable in relation to other investments such as cattle. There is no single answer to the debate, since there is much variation in the circumstances under which individual farmers operate, both within and between nations. The 'forced sales' situation has been documented by some authors in South Asia (e.g. Crow, 1987), while the 'wise farmer'

been found to apply in South-East Asia by Mears (1980) and Ellis *et al.* (1992). In the Sahelian countries of Africa, conflicting findings have been reported. Carefully documented work by Dioné (1989) has shown head taxes in Mali to have resulted in forced sales, but Berg and Kent (1991) report several authors who have reached opposite conclusions.

Another reason for not storing is the unpredictability of future prices, which often makes storage a risky business. This is particularly the case in countries such as Mali where prices vary widely from year to year, and do not follow a steady monthly trend. From Figure 1.1, it can be seen that Malian prices normally rise between harvest time and the lean season, but farmers who engaged in speculative storage in 1989 suffered significant losses. Storage was particularly risky as Mali was passing from a period of scarcity, when prices levels were related to the cost of imports, to a period of surplus, when they were related to the price at which Mali could export. Movement between surplus and deficit in the Sahelian countries probably explains the wide variation in Mali's prices from year to year.

Farmers may sell their grain at any time from maturity (sale of the standing crop) onwards. Sale at or before harvest has the advantage that the farmer is saved the cost and time involved in preparing the crop for storage. Transport, threshing, winnowing and drying are all passed on to other levels in the marketing chain, leaving the farmer free to attend to the next crop, or to other farm or off-farm activities. It has been estimated that post-harvest activities account for one quarter of the total cost of production even for small farmers in poor countries (Greeley, 1991 p.5). Early sale also reduces the risks of losses in post-harvest activities, and this is particularly advantageous in cases where the harvest occurs in the wet season.

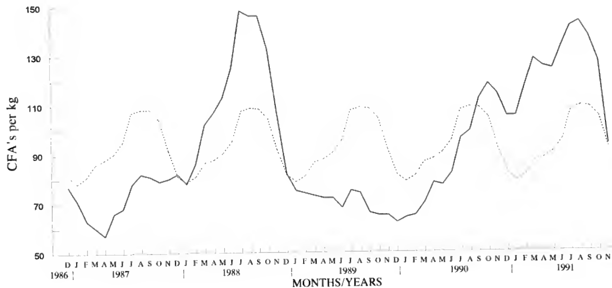
Trader Storage

The role of traders in cereal storage varies enormously between different parts of the world and between different crops. In most African countries traders carry out very little interseasonal storage of coarse grains, but buy and sell quickly, earning a moderate profit on each transaction. Most storage is carried out by farmers, and to a lesser degree by Government marketing boards and consumers who buy in anticipation of future household needs. Given a general situation of capital shortage, long-term storage of staple grains is insufficiently profitable to attract the interest of traders, who can earn more money by investing in fast moving consumer goods.

However the opposite is often true with rice in Africa. This crop is generally produced as a cash crop for the urban markets, but does not have a major demand for use as a staple in rural areas. Often much of the rice is imported and this has encouraged the emergence of large traders able to obtain finance major shipments and to negotiate advantageously with the authorities. Even when sourcing supplies from local producers, traders and millers must hold stocks to cover the needs of their urban clientele, and cannot rely on steady supplies arriving from rural areas.

In Asian countries, traders have a much larger role in interseasonal storage. The two major cereals are rice and wheat and both of these must be milled before reaching the consumer. This is unlike the situation in most of Africa where coarse grains such as maize, millet and

Figure 1.1. Retail Prices of Millet in Mali, 1986 - 1991
Annual Monthly Averages compared with Monthly Averages combined over 5 years



SOURCE: PRMC

.. 5-Year Combined Monthly Averages — Annual Monthly Averages

sorghum are the main staples. Typically African consumers buy these grains whole, and either grind them at home or take them to be ground at small custom-mills.
Large millers who become involved in the marketing chain tend to have good banking connections and can obtain capital at reasonable cost. Studies by the Natural Resources Institute (NRI) in Indonesia and Pakistan indicate, that wherever Government policy is conducive, millers enter the storage business on a large scale. In Indonesia, traders and millers store about 50% of that part of the rice crop which is carried over from the first harvest (Ellis *et al.*, 1992). Indeed it is common for them to store beyond the point when storage is profitable in its own right. This is because storage is only part of a business activity which involves milling and distribution of milled rice; millers must store in order to keep the mills running out of season, and to maintain supplies to regular customers. Losses on storage are more than compensated for by the gains on other operations.

In Pakistan, the millers' role in wheat storage has been limited by Government subsidies to public sector institutions, which procure about 60% of the marketed portion of the wheat crop. Rather than procuring wheat themselves, millers found it cheaper to procure from these Government institutions which carried out most of the long-term storage. However, when the Government raised their selling price in 1989 and thereby improved the incentives for millers to store, these responded promptly by buying up more stock.

In the future, storage behaviour in African countries will probably evolve towards the Asian pattern. The liberalisation of cereal markets will encourage the development of the private trade, the reform of banking systems should gradually increase traders' access to capital markets, and increased urbanisation and sophistication of tastes will favour the emergence of large milling enterprises.

Government Storage

As already mentioned, **Government** may become involved in storage for the purpose of stabilising prices and revenues to farmers. Related to this is Governments' overriding concern for national food security, which is fundamental to political stability. Governments therefore use storage to balance national supply and demand over time, and to minimise the risk of politically embarrassing shortages. They are thus attempting to supplement, and in some cases to replace, market mechanisms, on the assumption that the market can only achieve the balance with an unacceptable degree of supply and price fluctuation.

Governments do not involve themselves in the grain market only for reasons of national interest: they are often concerned with rewarding or placating particular lobbies or sectional interests. In developed countries farmers' interests often receive a high priority in Government decisions, out of proportion to their numbers. High 'support prices' encourage production in excess of demand, and surpluses have to be stockpiled at the taxpayers' expense. In many developing countries, the interests of the civil service and ruling party often take priority. Large national food reserves tend to be supported by the civil servants whose job it is to manage them, and by politicians who sometimes use their procurement and distribution as a means of dispensing patronage.

Governments may keep different types of storage reserve, depending on how much they wish to intervene in the grain market. Some of the options are:

(a) a **food security reserve** to be sold or distributed for free at times of extraordinary shortage or famine. Such reserves can be found in Sahelian countries like Mali and Chad. They are of limited size (e.g. 10% of the normal volume of grain marketed crop), and are usually limited to the amount thought necessary to tide the country over until the arrival of food aid or imports. They are not designed for the purpose of stabilising prices to producers and consumers. This is reflected in Figure 1.1 which shows that, since a reserve was created in Mali, monthly average retail prices have fluctuated by up to 260% of the lowest figure.

(b) a **price stabilisation stock**, as in the case of Indonesia. Here the Government has no monopoly role in grain procurement and distribution but buys and sells grains in competition with private operators. Average interseasonal retail price increases in Java are only 11% of the lowest monthly figure (Ellis *et al*, 1992). How much this extraordinary low figure is due to Government stockholding and how much to the stockholding activities of millers is a matter of debate.

(c) **national storage reserves** designed to supply most or all consumer needs in urban areas, and in rural deficit areas. In this case the Government has either a statutory trading monopoly, or a monopoly of all interregional shipments, and is the only party allowed to store significant quantities of grain. Between the 1960s and the early 1980s, such systems were the norm in many African countries, before the onset of liberalisation. Even now, the grain marketing systems in some countries, including Zimbabwe and Kenya, are still partially structured in this way.

Such Government operations usually benefit from public subsidy (intended or *de facto*) and capital investments are largely financed by overseas aid. Indeed subsidies are necessary if the public sector is to carry out functions which would not be profitable to the private sector. However, in some countries subsidies have allowed the State to 'crowd out' private sector competition. In the case of Pakistan for example, this phenomenon has resulted in the State handling about 60% of the marketable surplus. In many countries, such competitive advantages are outweighed by the high cost of fulfilling Government requirements (e.g. to buy and sell at fixed politically-determined prices, and to supply civil servants' consumption needs), overstaffing and slow decision-making processes. In such countries e.g. Tanzania in the 1980s, the official marketing agency may become insolvent and be gradually displaced by private sector competition.

Even relatively efficient Government trading operations face the problem that the more grain they buy, and the more they succeed in stabilising prices throughout the year, the less the incentive for private sector storage[1]. The responsibility for storage then falls very heavily on Government, and the private traders and millers concentrate on buying and selling quickly. Consequently, the Government finds that it has very high storage costs which it cannot recover through sale prices which have been politically determined. In the end the Treasury or Government banks must bale out the Government enterprise, thereby increasing the budgetary deficit.

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[1]. Pinkney (1987) estimated that in Pakistan a 15% increase in the public sector's gross trading margin would reduce the subsidy for grain procurement from about US$175 million to US$65 million.

Since 1981, there has been a major move to liberalise grain marketing systems in developing countries, and this has been stimulated by both donor pressure and the massive budgetary deficits stemming from the operation of Government marketing boards. Many African Governments are opting for the first of the above options i.e. a limited food security reserve.

Some countries do not appear to need any reserve stocks but can rely on international trade to assure food security and to stabilise prices. This is particularly the case with some deficit countries in Africa, such as Swaziland and Namibia, who have good communications with the world market and are close to major grain suppliers.

Lastly there are some countries where it would seem most appropriate for Government to maintain some sort of price stabilisation role. Such is the case in landlocked countries like Zimbabwe and Malawi, whose production fluctuates between surplus and deficit. If the Governments of these countries totally withdraw from price stabilisation, prices are likely to be subject to very wide interannual fluctuations, with adverse effects on production incentives and consumer welfare (Pinkney, 1993). Nevertheless these countries still have major scope for liberalisation. By improving port facilities and communications with the outside world, and by developing intra-regional trade, they can greatly reduce the required level of stockholding.

The move towards liberalisation in developing countries contrasts with the situation of the developed countries, where Governments are still heavily involved in the grain trade. Developing country officials often ask why they should be asked to liberalise while rich countries fail to do so. The answer is simply that these countries have the wealth to support their farmers at the expense of their non-farming majorities.

Farmers, traders and governments all have reasons to store grain, but they also have reasons for limiting the amount of storage. The unit costs of storage tend to be constant (or to decrease slowly) as larger quantities are stored, but the benefits fall off as more is stored. In deciding how much to store, the benefits must be balanced with the costs involved (see Figure 1.2).

IMPROVEMENTS IN LARGE-SCALE STORAGE AND HANDLING

How improvements have taken place

Until now, most large-scale storage of cereals in developing countries has been carried out by Government marketing boards, which have developed their activities with the technical and financial assistance of donors and international financial institutions. This has resulted in the building of large numbers of grain stores and mills, with a gradual increase in scale and the degree of technical sophistication. In some countries this has helped maintain food security and feed urban populations growing at 5% or more per annum. However there has also been much wastage, with stores often being inadequately located, inappropriately designed, and poorly managed and maintained. Stores have been built to support Government monopolies, on the assumption that no storage would be carried out by the private sector, but in the event of liberalisation, much of the capacity has been found unneeded and poorly located. Thus the National Milling Corporation in Tanzania has over

400,000 tonnes of storage capacity for which it must find new uses, to which must be added the large storage capacity of the State-sponsored cooperative unions.

Most grain stores have been designed for bag handling, reflecting the low cost of manual labour and the lack of spare parts and maintenance support needed for mechanical handling equipment. However bulk handling has been introduced throughout the developing world, with results which leave much to be desired. Too often, Marketing Boards have been unable to make good use of these facilities and they have become rusting monuments to inappropriate development assistance.

In international development assistance programmes, there is often much support for 'modern' capital-intensive systems. This was observed in a study commissioned by the Pakistan Agricultural Research Council (Coulter, 1991). Between 1983 and 1987 no less than five feasibility studies advanced the case for investments in bulk handling. All the studies had used questionable assumptions, and four out of the five studies had assumed reductions in storage losses of 5% or more simply by switching from bag to bulk handling. Given that loss surveys have revealed storage losses of between 1.5% and 3.9% such reductions would have been impossible.

The case for bulk handling

There are, however, instances when bulk handling is economically justified in developing countries. This is usually at bottle-necks in the marketing chain, and where grain has to be handled in large volumes and at great speed, for example at port facilities, railway terminals or at mills. In such cases, investment in bulk handling facilities will often result in major cost savings, due to reduction in demurrage charges and down-time. The investment in one capital asset (bulk-handling equipment) produces major savings in the use of other capital assets (ships, trains, mills etc.). In most developing countries, labour costs are unlikely to be significant in the calculations, but bulk handling will reduce the risk that labour problems, strikes etc. will slow operations or bring them to a halt.

Bulk handling tends to be least viable for the long-term storage of grain, where stocks are only turned over once a year or less. In such cases the savings in labour and bags are unlikely to cover the high capital cost in silos, handling equipment etc. With well-run bulk storage complexes it may be possible to achieve a marginal reduction in storage losses but, due to poor operation and maintenance, losses are sometimes increased.

Bulk handling may also result from changes in farming methods. The introduction of combine harvesters in certain countries provides an incentive to start handling the grain in bulk. From the tank of the harvester the grain can be transferred mechanically to a bulk truck, from there to a bulk store or silo, and from there to a mill. This completely eliminates the use of the bags in the system, and overcomes problems of labour shortage and congestion which sometimes occur with a bag handling system. However in irrigated or high rainfall areas, the main benefit to the farmer may be by making it easier for him/her to plant a second crop on the same land.

Even where the economics of bulk handling are favourable, there are other reasons for caution. Most notably one should carefully assess whether the operating company or Mark-

Figure 1.2: Balancing the Supply and Demand for Storage.

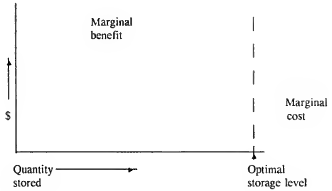
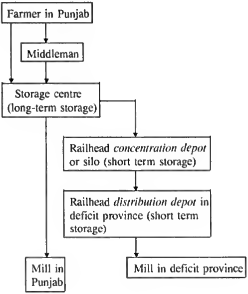


Figure 1.3: Alternative Logistical Arrangements



eting Board can obtain power, fuel, spare parts and qualified staff at all times and in sufficient quantities to operate and maintain bulk handling machinery. It should also be noted that some commodities, including milled rice and small grains, are difficult to handle in bulk. Paddy rice and wheat varieties such as *Mexipak* are abrasive, and require the use of special equipment such as rubber bucket elevators. Bulk handling also poses problems for commodities which must be handled in many different grades or small lots. For further guidance on how to decide between bag and bulk systems readers are referred to a useful bulletin published on this subject by NRI (Friendship and Compton, 1991).

Appraising the case for improvements

Technical improvements must be appraised within the context of a **total commodity system**. This includes the chain of activities linking farmers and consumers, suppliers of goods and services to the participants in that chain (banks, equipment suppliers etc.) and Government policy and regulatory activity. A four step approach is recommended based on an appraisal of the case for bulk handling in Pakistan (Coulter, 1991):

Step 1: Fully understand the policy environment

As Governments gradually move towards more liberalised systems, public policies towards grain marketing are in a state of flux. If planning is possible at all, it is important to plan for tomorrow's system and not for today's. One needs to ask the following questions:

What types of reserves does the Government wish to hold?
Where?
What is the level of stockholding considered desirable?
What pricing regime will the Government operate?
Will the system be subsidised and by how much?
What will be the role of the private sector?
Is this system sustainable? Can it be financed, managed and maintained?
How is the system likely to change in the future?

Step 2: Understand the operating company (e.g. Marketing Board) which is supposed to implement the project

Here one needs to carry out an institutional appraisal, with a view to understanding the way in which the company operates, the capability of staff and their perceptions of the current situation and any proposed changes. This will involve interviewing Directors and company staff from Chief Executive down to the level of store attendant.

Step 3: Identify possible improvement scenarios

In the Pakistan study, there were various alternatives to consider, involving different logistics, storage technologies, and mechanising different stages in the marketing chain, as follows:

(a) Alternative logistical arrangements:

The public sector handling system at the time of the study was more complicated than the system illustrated in Figure 1.3, having additional handling and storage operations which might be eliminated by rationalisation. It would be unwise to convert this existing system to bulk handling as this would compound logistical inefficiencies. For this reason it was assumed that bulk handling would be introduced within a rationalised system of the type illustrated above. The economics of bag and bulk alternatives are compared along this logistically efficient system.

(b) Various alternative storage technologies:

Bag systems	Standard warehouses ('house-type godowns'); Permanent plinths (outdoor storage with bags stacked on plinths and covered by tarpaulins).
Bulk systems	Concrete silos; Steel silos; Bulk warehouses; Open bulkheads (grain held outdoors between pre-fabricated steel walls and covered with PVC sheeting).
Bag-cum-bulk	Using standard warehouses, with grain stored in bulk within bag walls.

(c) Mechanisation of different stages in the marketing chain, as follows:

Converting only the mills for reception and handling grain in bulk (preliminary calculations showed this to be the most obvious place to start conversion);

Bulk handling from reclaim (i.e. unloading of grain for dispatch) at the storage centre to the mill;

Bulk handling from reception of grain at the storage centre to the mill;

Bulk handling from the market to the mill;

Bulk handling throughout the whole chain, from harvest to mill.

Step 4: Appraise the improvement scenarios and draw conclusions

The scenarios considered involved various permutations and combinations of logistics, storage technology, and the stages of the chain to be converted to bulk. For each scenario, the case for bulk handling was appraised alongside the bag handling alternative, using cost-benefit analysis (CBA). Only those costs likely to differ between the two alternatives were included in the calculations. The methodology of CBA and its application in the Pakistan project are discussed in Annex 1.

Table 1.1 shows the results obtained for just one of the scenarios considered, i.e. deciding which type of store should be used when building new long-term storage facilities. The cheapest technology is the permanent plinth, cost per tonne estimated at US$6.1 per tonne, compared to warehouses $13.9, concrete silos $14.8 and bulk warehouses $9.4. The cost of the open bulkhead system ($6.8) is similar to the permanent plinths, but this technology is unproven under Pakistani conditions, and effective pest control is likely to prove difficult.

This finding was interesting because investment programmes had concentrated on funding the construction of warehouses and to a lesser extent bulk storage, but had completely ignored the possibility of building permanent plinths, which were suitable in the dry conditions of Pakistan. To store the same quantity of grain, plinths require a capital investment of less than one sixth that for standard warehouses and about one eighth that for concrete silos.

The other analyses did however confirm that there was a good case for using bulk handling in port facilities, in the intake and handling of wheat at flour mills and (subject to thoroughgoing reform of the railways) for long-haul shipment by rail.

IMPROVEMENT TO STORAGE ON THE FARM

The case for improvements in storage

As indicated previously, storage involves substantial costs and risks as well as potential benefits for farmers. Storage competes with other activities valued by farm family members, and it is necessary to understand where storage fits in to the entire farming system and household economy in order to assess the need for interventions and the probability of their uptake.

Over the past two decades the need for economic and social analysis in the planning and design of storage interventions has become more widely recognized. This stems from the realization that any 'improvements' in storage will only be attractive to farmers, traders or governments if the perceived benefits substantially outweigh the costs. Technical superiority is generally insufficient (although it can be attractive for its prestige value), and farmers and traders are likely to tolerate quite high storage losses before undertaking complex or expensive changes to their storage systems. An understanding of the reasons why people store, and the systems within which storage occurs, is necessary in order to estimate how the benefits and costs of innovations are likely to be assessed by the intended users of the technology.

Rates of adoption of new storage technologies at the farm level have often been disappointing (Phillips 1981; Compton, 1992). In some cases, projects have failed because they were promoted on the basis of assumptions which turned out to be false. Sometimes it was incorrectly assumed that storage ranked high among farmers' lists of priorities. From such experiences it can be concluded that, before storage projects are implemented, there is a general need for more research into the economic and social factors involved.

Table 1.1. COMPARISON OF COSTS FOR NEW PERMANENT STORAGE FACILITIES, USING DIFFERENT STORAGE TYPES, FOR LONG - TERM STORAGE OF GRAIN

(cost US $ per tonne of wheat)

	With Bag Handling			With Bulk Handling			
	(a) Standard Warehouse	(b) Bag - cum - Bulk System	(c) Permanent Plinths	(a) Open Bulkheads (average of high and low costs)	(b) Concrete Silos	(c) Steel Silos (low cost estimate)	(d) Bulk Godowns
(a) At storage centre :							
FIXED COSTS :							
- Capital cost	8.6	5.7	1.3	3.4	11.5	6.8	7.1
- Maintenance	1.0	0.9	0.1	0.7	2.4	1.8	1.2
VARIABLE COSTS :							
- Materials cost	0.9	0.4	1.3	1.3	0.2	0.2	0.2
- Fuel / power				-	0.1	0.1	0.1
- Labour	0.8	1.0	0.8	0.6	0.2	0.2	0.4
- Bags	1.0	1.0	1.0				
- Losses (2 x 0.1 %)	0.4	0.4	0.4	0.4			
Sub - total :	12.7	9.4	4.9	6.4	14.4	9.1	9.0
(b) At mill :							
FIXED COSTS :							
- Capital costs				0.2	0.2	0.2	0.2
- Maintenance				0.1	0.1	0.1	0.1
VARIABLE COSTS :							
- Fuel / power				0.1	0.1	0.1	0.1
- Labour	0.3	0.3	0.3				
- Bags	0.7	0.7	0.7				
- Spillage (0.1 %)	0.2	0.2	0.2				
Sub - total:	1.2	1.2	1.2	0.4	0.4	0.4	0.4
Total:	13.9	10.6	6.1	6.8	14.8	9.5	9.4

NOTE : Only costs which differ between the various options are shown. Capital cost assumes opportunity cost of capital of 10 %.

Source : Coulter (1991)

It is also now generally accepted that local, established storage systems are usually well adapted to local conditions, and losses from grain storage are already low and acceptable to farmers (Greeley 1987, Compton 1992). This is not to say that improvements cannot be made. Indeed, the following factors point to an increased need for improvements in the handling and storage of grain at various levels in the system.

(i) Increasing urban demand

Due to demographic changes urban population in most developing countries is growing at 5% or more per annum. In addition many countries, particularly those in Asia, are experiencing massive increases in intensive animal production, creating large markets for feed grains. For example, Indian poultry production grew by about 9% per annum in the 1980s. Consequently an increasing proportion of grain production is destined for the market rather than subsistence use, increasing storage requirements on the farm and elsewhere in the marketing chain.

(ii) Changes in government policy

Structural adjustment programmes and market liberalization in a number of African and Asian countries are increasing the role of the private sector in storing produce which is surplus to subsistence requirements. It was noted previously that in most African countries, traders and millers are not heavily engaged in storage, and this means that farmers in surplus producing areas are having to greatly increase their storage activity.

(iii) Changes in the farming system

On-farm and off-farm storage systems have been affected by technical change in other aspects of the farming system. The *green revolution* has involved the adoption of new varieties which are often more susceptible to storage losses (Golob and Muwalo, 1984). It has proved difficult for plant breeders to combine higher yields with storage durability, since the very qualities which lead to higher yields, and therefore (potentially) increased income also make the grain more attractive to pests. Thus, high yielding varieties of maize tend to give large, soft grains with less husk cover than traditional varieties.

Short duration varieties have allowed for increased cropping intensity. This can give rise to further storage problems when one of the harvests occurs in the wet season, making it difficult for farmers to dry the grain sufficiently for storage. Farmers in some areas have responded to the situation by growing high yielding varieties for immediate sale, and traditional varieties for storage and on-farm consumption (Giga and Katarere, 1986).

High yields also imply that farmers may need to manage the storage or sale of larger quantities of grain within a shorter space of time, which in itself may cause problems and encourage farmers to sell at harvest, in order to free up the labour for field preparation of the next crop. In some cases labour constraints at harvest lead to early or late harvesting of the crop, with consequent losses (Compton, 1992).

(iv) Changes in the pest population

A major change in the incidence of pests can prompt farmers to seek new storage technologies. In Tanzania the larger grain borer, a destructive pest of stored maize and cassava, was introduced from its native habitat in Central America in the early 1980s. Farmers were reported to have suffered up to 30 per cent losses from the new pest. In response to their demands the government, with donor assistance, implemented a successful extension programme to control the pest.

The larger grain borer has now spread to a number of other East and West African countries, including Kenya, Togo and Ghana, but losses in these countries have not yet reached the levels recorded in Tanzania.

What factors must one consider in assessing the potential for on-farm improvements?

The first step in the identification of appropriate technology is the assessment of the needs of potential users. In the case of post-harvest technology, claims of high losses and of the potential for reducing them have provided a major justification for the promotion of new technologies. The issue is discussed below in the next sub-section.

Whether or not there are good quality data on losses, it is also important to investigate the potential **demand** for the technology by its intended users. Even if losses appear quite high, it may be that post-harvest problems do not rank high among farmers' priorities. It may also be that they are more concerned to reduce labour or other costs than they are to reduce losses. Mechanical threshers and mills have been widely adopted in Bangladesh even though they tend to increase losses, because of the savings in labour costs (Greeley, 1987). As a result women labourers from poor households have lost a source of income from hand threshing and milling.

Even where there is a demand for loss reducing technical changes, farmers may find it difficult to adopt recommended technologies, because of cash flow problems, labour constraints, lack of materials, or storage chemicals. Small farmers and traders often find it difficult to obtain credit at reasonable interest rates, since formal financial institutions consider loans to them be too risky.

If it is decided that some form of intervention is both desirable and feasible, then the full range of options should be considered. For example, if storage losses are high, then, in addition to investigating storage technologies, the potential for altering cultivation and post-harvest activities (e.g. shelling maize instead of storing it on the cob), for introducing varieties with improved storage characteristics, or for experimenting with biological control methods can also be examined. A discussion of a wide range of options is given in Compton (1992).

Notwithstanding these options, the most successful storage technology to date appears to be the use of insecticides. They can easily be integrated into existing storage systems, and often give high returns. The main constraints on increased insecticide use are: availability of appropriate insecticides at the right time; stability of the formulations used; farmer training

in the correct types and correct use of insecticide; cost, which sometimes renders their usage uneconomical.

In view of the latter, it may be appropriate to use locally available materials, such as wood-ash, sand or certain plant materials which control the growth of insect populations. Use of such materials is most likely to be viable where small quantities of grain are involved, for example in storing locally produced seeds. When farmers have to store larger amounts of grain (e.g. a tonne), usage of such materials may prove tedious and cumbersome, and sufficient quantities of them may not be available. At the same time some of these materials may have toxicological effects which have yet to be investigated. Research in the coming years should throw more light on the usability of a range of these materials.

Introducing new store types has often proved difficult. The main reason is that the capital cost of new stores is too high, and often fails to offset the reduction in the value of losses, especially where stores are not used to full capacity. There have been notable successes in the introduction of metal bins in Swaziland, Central America and the Punjab area of India and neighbouring Pakistan, but no such cases are known of in poorer areas of Africa. For similar reasons, mechanical driers have also been difficult to promote. Unless there are severe drying problems, sun drying tends to be preferred since it is cheaper. The improved quality of mechanically dried grain is rarely reflected in a higher price, and therefore provides no incentives for farmer adoption.

As well as assessing the level of losses and the demand for the new technology, one must also appraise the *cost-benefit* or **financial viability** of the improvement to the individual farmer. The next three sub-sections discuss the assessment of the three factors highlighted above, i.e. losses, demand and financial viability.

(i) Assessment of storage losses

Losses can occur at several stages of the post-harvest chain, including threshing, storage, transport, milling, wholesale and retail distribution. In order to decide whether it is worth taking action over losses of any sort, one should obtain information on losses at all these stages.

There has been a tendency to overestimate storage losses, and to base estimates on extreme cases or guess-work rather than on sound empirical testing. Figures of 30 per cent or more are not uncommon (Greeley, 1987, p.13ff). By contrast, the results of detailed field studies suggest that under traditional storage systems in tropical countries losses are typically around 5 per cent over a storage season (Tyler and Boxall, 1984), depending upon the crop, the ambient conditions, the period of storage and other factors. Somewhat higher levels have been encountered in the wetter parts of West Africa and Central America.

Loss figures around the 5% level should not however be considered insignificant. Firstly it should be noted that physical losses are usually accompanied by qualitative losses affecting the mass of the grain in store. Secondly the losses are mainly experienced during the lean season before the new harvest is ripe, thereby having an adverse effect on the food security of farming families at a particularly critical period. In Honduras, farmers' feelings of insecurity about this period have been an important motive for adopting metal storage bins.

Even where detailed studies are undertaken, there are a number of methodological difficulties involved in estimating losses (Greeley, 1991). Loss assessment methods tend to be slow and to require skilled field and laboratory staff. They are often undertaken on experimental sites, making it difficult to relate the results to on-farm situations.

There are a number of factors which tend to lead to an upward bias in the loss estimates. Firstly, extremes may be taken rather than averages. Ideally the sample size and standard deviation should be quoted with the loss estimate to avoid this. Secondly, removals from store over the season are not always accounted for. Where removals do occur, percentage losses calculated on the basis of grain remaining in store will be overestimates. Another source of overestimates lies in treating partial damage as a total loss, when in fact the damaged grain would be used by farmers for home consumption or animal feed. A fourth source of upward bias lies in the potential for double counting losses at different stages in the post-harvest system. Losses at one level are related to those at other levels.

Another difficulty in using estimates of losses to justify technical change is the problem of assigning to the losses a value which makes sense to the potential user of the technology. The most common form in which losses are expressed is as a percentage weight loss. But what is important from the farmer's point of view is the use that the grain can be put to, or the market price that will be received. Grain intended for sale may be consumed, or that intended for consumption used as animal feed.

A rapid loss assessment method for estimating storage losses in maize and cassava has recently been developed in Togo (Compton *et al.* 1992). The method attempts to incorporate farmer criteria in defining categories of loss, and since the measurement occurs in the field, rather than at a laboratory, results can be discussed with farmers on the spot. Such methods could usefully be integrated into post-harvest technology projects.

(ii) Assessment of demand

As in all market research one should start with desk research, including the interviewing of key informants, to gain whatever data are readily available about storage systems, the uptake of improvements introduced in the past and other relevant information.

One should then visit representative villages in the area of interest to analyse the farming system together with the farmers (i.e. carry out a *participatory rural appraisal* or *PRA*) to identify opportunities for improvements, taking care to interview a representative sample of farmers and womenfolk, including significant minority groups likely to have an important role in crop storage (e.g. larger mechanised farmers). Out of this activity should come: (a) an assessment of whether any improvements are worth considering in greater depth; (b) a list and description of these ideas or *concepts* suited to particular groups of farmers.

Selection of technologies may be aided by means of **matrix analysis**. This involves tabulating the alternative technologies (on a horizontal axis) against the full range of criteria used in their selection (on a vertical axis). Each technology can be scored or ranked in terms of the respondents' perception of its performance against each criterion. The different steps to be considered in matrix analysis are outlined in the shaded box on the next page, using

HOW TO DO MATRIX SCORING

1. Find a group of key informants who are knowledgeable and willing to discuss. Hold an open-ended discussion with them about on-farm storage. This should be along the lines of a 'focus-group interview', with the moderator guiding the discussion in a non-directional manner, with occasional prompts, and asking for clarification of points of interest.

2. As the discussion proceeds, ask the participants to consider a range of alternative storage structures. Ask them which are of interest, and the pros and cons are for each. Probe for further criteria.

3. Based on the discussion, make a short list of (a) storage structures worthy of further consideration, and (b) the most important criteria by which the informants appraise their suitability. Then construct a matrix with the storage structures displayed on the horizontal axis, and the criteria on the vertical axis. This can be done on a large sheet of paper, or on the ground (using seeds, stones etc. for scoring).

4. Make negative criteria positive (e.g. 'attracts pests' is written on the chart as 'does not attract pests').

5. Convene a group of villagers to assess each storage structure following the list of criteria. Structures may be scored on a scale of, say, ten points. If many items have to be compared, a smaller scale with less points can be used. The highest total score will indicate the most preferred.

6. Ask which criteria are most important? If it emerges that some criteria are far more important for the villagers than others then give them more weight by multiplying their scores by a weight factor (e.g. 2).

Adapted from: J. Mascarenhas, Participatory rural appraisal and participatory learning methods, recent experience from MYRADA and South India; Forests, Trees and People Newsletter No. 15/16.

This exercise can be carried out with people representing different social groups.

the appraisal of alternative storage structures as an example. Typical results are displayed in Figure 1.4.

The same approach could be used in assessing pest control systems, or other technologies.

Figure 1.4. Matrix Scoring for three grain storage structures

	Metal bin	Improved crib	Traditional crib
Durability of structure	***** ***	*****	**
Ease of handling	***** *	***** *	****
Peace of mind	*****	***	***
Low construction costs	*	***	***** *****
Does not attract pests	***** **	****	**
Total Score:	27	21	21

In this case the metal bin has the highest score. However, if 'low construction costs' were of leading importance to the villagers, resulting in the multiplication of its scores by two, then the traditional bin would come out top, with 31 points, compared to 28 and 24 respectively for the other two constructions.

As an alternative to scoring, data may be ranked against each criterion, 1 = best, 2 = next best, etc.. Ranking can be used for up to 7 items. The method is straightforward and rapidly elicits much information on why participants give priority to certain criteria. However ranked data for different criteria cannot be added up. Ranking only conveys an order of preference, but not the degree of liking or disliking.

By this stage it may be concluded that certain technologies are affordable and can be field tested without further research. Where this is not the case however, or where one is approaching a number of villages with different characteristics, one may proceed to appraise the different options through **concept testing**. This market research technique was introduced by NRI into Swiss-funded storage projects in Central America, and is now used for the rapid appraisal of storage concepts, without going to the expense of constructing prototypes.

In a concept test, respondents (chosen from the target population) are shown a picture or mock-up of the new storage structure with a list of their key attributes, and then answer questions about likes and dislikes, how and when he/she would use the store, willingness to invest in one, preference between alternative concepts and so on. The tests can be carried out in individual depth interviews or in group interviews, or in a combination of both.

The tests can yield some quantitative information e.g. about the percentage of respondents wishing to invest in the structure, about their ranking of technologies etc., but above all it produces in a short space of time a lot of qualitative insights into farmers' thinking about storage and its place in the farming system and the household economy.

(iii) Assessment of financial viability in on-farm storage and handling

On-farm improvements offer the potential for an increase in net benefits through a reduction in variable costs, such as labour, a reduction in the value of grain losses, or an increase in the market value of the grain as a result of using the technology.

An example of the use of cost-benefit analysis (CBA) on farm-storage projects is that undertaken by Boxall and Bickersteth (1991). They compared seven different storage technologies in terms of the break-even price which the farmer must obtain on one bag of maize to cover storage costs, at two different discount rates. Their findings are presented in Table 1.2, and details of the methodology used are shown in Annex 1.

They found that traditional systems with lower capital costs and no operating costs achieve lower break-even prices in spite of higher losses. Various development programmes had favoured the *improved storage crib*, but this technology proved the least favourable on account of its high capital costs. Only in areas with particularly high losses would the improved crib be financially viable. The mud bin was the most cost-effective structure because of its durability, cheap construction cost and low losses.

The conclusion reached was that storage technologies currently being recommended under certain development programmes would not, under normal circumstances, be profitable for farmers. Similar findings were encountered in two other West African studies (Al Hassan, 1989; Stabrawa, 1992).

Marketing of new on-farm technology

Having established that a given concept is desired and financially viable, one can then proceed to *test-market* the technology, by persuading farmers in a given locality to build or install prototypes. As with any other marketing exercises, the test-market will need to be supported by a delivery structure (involving artisans, trainers etc.), after-sales service and maybe credit. The demand for the technology should be monitored through the growth of sales in the target area, and the level of *market penetration* i.e. the number of units installed/potential number installed. Reasons for non-adoption should be analysed, with a view to either changing the product or the marketing strategy, or revising downward one's view of market potential. Figure 5 summarises NRI's approach to technology assessment and dissemination in Guatemala.

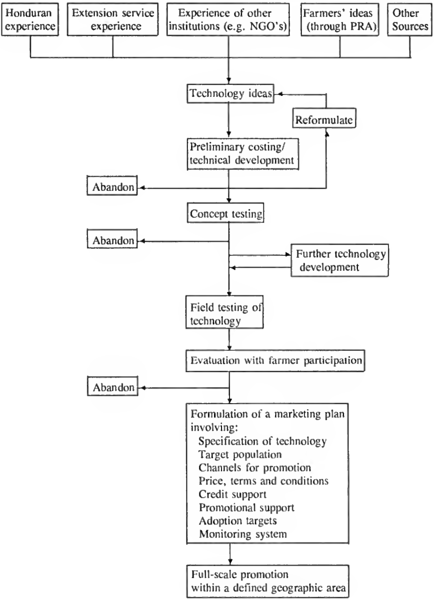
Table 1 2 GHANA - MAIZE STORAGE COSTS

(In Cedis ; Cedis 360 = US$ 1)

	STORE TYPE	ASHANTI CRIB	EWE BARN	NORTHERN BASKET	NORTHERN MUD BIN	IMPROVED CRIB	SACKS IN HOUSE	ASHANTI CRIB WITH INSECTICIDE
1	Capital Cost							
	Materials	1000	1000	2000	0	18500	400	1000
	Labour	3500	1000	1000	1500	3000	0	3500
	Total	4500	2000	3000	1500	21500	400	4500
	Capacity (shelled bags)	10	10	10	10	17	1	10
	Cost / bag	450	200	300	150	1265	400	450
	Life of structure (yrs)	4	3	4	10	4	2	4
	Annualised cost (real interest + capital)							
	at 10 %	142	80	95	24	399	230	142
	at 20 %	174	95	116	36	488	262	174
2	Operating Costs (Cedis / bag)							
	Actellic Dust # (50 g)					150	150	150
	Labour to shell , treat and fill sack *					100	100	100
	Sacks					100	0	100
	Actellic EC to spray cobs **					113		113
	Total	0	0	0	0	463	250	463
3	Opportunity cost of stored grain + +	600	600	600	600	600	600	600
4	Losses (Value ##)	400	400	80	80	40	80	80
5	TOTAL STORAGE COST at 10 %	1142	1080	775	704	1501	1160	1284
	at 20 %	1174	1095	796	716	1591	1192	1316
6	Cost of grain prior to storage	4000	4000	4000	4000	4000	4000	4000
7	BREAK - EVEN PRICE ## at 10 %	5142	5080	4775	4704	5501	5160	5284
	at 20 %	5174	5095	4796	4716	5591	5192	5316

NOTES
(1) Real interest rates account for inflation over the period of storage
(2) Labour Shadow Price = Cedis 250
(3) # Actellic Dust Cedis 1500 / 500 g
(4) * 2 5 bags in one man / day
(5) ** Actellic EC Cedis 7500 / litre can treat 200 bags of cobs
(6) + + Product of value of maize and current annual savings rate (15 %)
(7) ## Farmgate price of one bag of maize in September 1991 (Cedis 4000)

Figure 1.5. Schematic presentation of Technology Dissemination



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CHAPTER 2

THE BIODETERIORATION OF GRAIN AND THE RISK OF MYCOTOXINS

BIODETERIORATION

The condition of stored grain is determined (Lacey, 1988) by a complex interaction between the grain, the macro- and micro-environment and a variety of organisms (including micro-organisms, insects, mites, rodents and birds) which may attack it.

Grain provides an abundant source of nutrients, and the natural consequence of the type of stable ecosystem described above will normally be spoilage (biodeterioration) of the grain, caused by the organisms.

The extent of contamination by moulds is largely determined by the temperature of the grain and the availability of water and oxygen. Moulds can grow over a wide range of temperatures, from below freezing to temperatures in excess of 50°C. In general, for a given substrate, the rate of mould growth will decrease with decreasing temperature and water availability. Moulds utilise intergranular water vapour, the concentration of which is determined by the state of the equilibrium between free water within the grain (the grain moisture content) and water in the vapour phase immediately surrounding the granular particle. The intergranular water concentration is described either in terms of the equilibrium relative humidity (ERH, %) or water activity (a_w). The latter describes the ratio of the vapour pressure of water in the grain to that of pure water at the same temperature and pressure, while the ERH is equivalent to the water activity expressed as a percentage. For a given moisture content, different grains afford a variety of water activities and, consequently, support differing rates and type of mould growth. Typical water activities which are necessary for mould growth range from 0.70 to 0.90.

The interaction between grain temperature and moisture content also affects the extent of mould colonisation. The passage of water from the grain into the vapour phase is encouraged by an increase in temperature. Consequently, for a given moisture content, the water activity, and the propensity for mould growth, will increase with temperature. Maize, for example, can be relatively safely stored for one year at a moisture level of 15 per cent and a temperature of 15°C. However, the same maize stored at 30°C will be substantially damaged by moulds within three months.

Insects and mites (arthropods) can, of course, make a significant contribution towards the biodeterioration of grain, through the physical damage and nutrient losses caused by their activity. They are also important, however, because of their complex interaction with moulds and, consequently, their influence on mould colonisation.

In general, grain is not infested by insects below a temperature of 17°C whereas mite

infestations can occur between 3 and 30°C and above 12 per cent moisture content. The metabolic activity of insects and mites causes an increase in both the moisture content and temperature of the infested grain. Arthropods also act as carriers of mould spores and their faecal material can be utilised as a food source by moulds. Furthermore, moulds can provide food for insects and mites but, in some cases, may may also act as pathogens.

Another important factor that can affect mould growth is the proportion of broken kernels in a consignment of grain. Broken kernels, caused by general handling and/or insect damage, are predisposed to mould invasion of the exposed endosperm. It has been estimated, for example, that increasing the proportion of broken grains by five per cent will reduce the storage-life of that consignment by approximately one order of magnitude; that is from, say, 150 to 15 days.

Mould growth is also regulated by the proportions of oxygen, nitrogen and carbon dioxide in the intergranular atmosphere. Many moulds will grow at very low oxygen concentrations; a halving of linear growth, for example, will only be achieved if the oxygen content is reduced to less than 0.14 per cent. Interactions between the gases and the prevailing water activity also influence mould growth.

MOULDS AND MYCOTOXINS

The interactions described above, within granular ecosystems, will support the growth of a succession of micro-organisms as the nutrient availability and microenvironment changes with time. In the field, grains are predominantly contaminated by those moulds requiring high water activities (at least 0.88 a_w) for growth, whereas stored grains will support moulds which grow at lower moisture levels. The rate of mould growth is also determined by the ability of the micro-organism to compete with other species. Some species, including those of *Aspergillus, Penicillium* and *Fusarium*, can occur both in the field and in storage.

Secondary metabolites are those compounds, produced by living organisms, which are not essential for growth. Some secondary metabolites produced by moulds are highly toxic to animals, humans and plants. These so-called 'mycotoxins' have been extensively studied since 1961, when a group of highly toxic *Aspergillus flavus* toxins - the aflatoxins - were isolated from a consignment of groundnut meal which had been imported into the UK (Coker, 1979).

Any activity which disturbs the stability of an ecosystem will increase the production of secondary metabolites, including mycotoxins. Such activities include the widespread use of fertilizers and pesticides, high yielding plant varieties and the cultivation of a limited number of plant species with restricted genetic variation. The normal practices of harvesting, drying and storage also, of course, significantly disturb the ecosystems of grains established before harvest.

The major mycotoxin-producing moulds include (Miller, 1991) certain *Aspergillus, Fusarium* and *Penicillium* species. Toxigenic (mycotoxin-producing) *Aspergillus* moulds can occur both before and after harvest, whereas *Fusarium* and *Penicillium* moulds occur predominantly before and after harvest respectively. In general, *Aspergillus* is associated with the tropics

and *Penicillium* with temperate climates, whereas *Fusarium* moulds occur worldwide. However, because of the complexity and variety of ecosystems supporting mould growth in grains, the nature and extent of the worldwide occurrence of moulds and mycotoxins cannot, as yet, be confidently defined. About 300 mycotoxins have been reported, produced by a wide variety of moulds. A few of the major moulds and mycotoxins are listed in Table 2.1 and discussed in the following sections of this Chapter.

Table 2.1. The major moulds and mycotoxins.

Mould species	Mycotoxins produced
Aspergillus parasiticus	Aflatoxins B_1, B_2, G_1, G_2
A. flavus	Aflatoxins B_1, B_2
Fusarium sporotrichioides	T-2 toxin
F. graminearum	deoxynivalenol (vomitoxin) zearalenone
F. moniliforme	fumonisins
Penicillium verrucosum	ochratoxin A

THE SIGNIFICANCE OF MYCOTOXINS

Mycotoxins have been implicated in a range of human and/or animal diseases and occur in a variety of grains. The ingestion of mycotoxins can produce both acute (short-term) and chronic (medium/long-term) toxicities ranging from death to chronic interferences with the function of the central nervous, cardiovascular and pulmonary systems, and of the alimentary tract. Some mycotoxins are carcinogenic, mutagenic, teratogenic and immunosuppressive. Aflatoxin B_1 (Figure 2.1a), for example, is one of the most potent hepatocarcinogens known.

The mycotoxins have attracted worldwide attention, over the past 30 years, firstly because of their perceived impact on human health, secondly because of the economic losses accruing from condemned foods/feeds and decreased animal productivity and, thirdly, because of the serious impact of mycotoxin contamination on internationally traded commodities. It is estimated, for example, that the cost of managing the mycotoxin problem on the North American continent is approximately \$5 billion.

The Aflatoxins

The aflatoxin-producing moulds *Aspergillus flavus* and *A. parasiticus* occur widely, on inadequately dried food and feed grains, in sub-tropical and tropical climates throughout the world. Pre-harvest mould growth, and aflatoxin production, is encouraged by insect damage, mechanical damage, drought stress and excessive rainfall. The aflatoxins may occur, both before and after harvest, on virtually any food or feed which supports fungal growth, including cereals, oilseeds and edible nuts. Maize, groundnuts, cottonseed, oil-palm kernels and copra are particularly associated with the occurrence of the aflatoxins. The very substantial international trade in these commodities serves to amplify the worldwide nature of the aflatoxin problem.

The ingestion of aflatoxin B_1-contaminated animal feed, by dairy cattle, can result in the presence of aflatoxin M_1 (Figure 2.1e) - a metabolite of aflatoxin B_1 - in milk. This is an issue of considerable importance to public health, given the frequent consumption of milk and dairy products by infants.

Aflatoxin B_1 has been confirmed as a highly potent human carcinogen, whereas the carcinogenicity of the aflatoxins G_1 (Figure 2.1c) and M_1 has been confirmed only in experimental animals.

The acute toxicity of the aflatoxins has been demonstrated in both animals and man. The outbreak of 'Turkey X' disease in the UK, in the early 1960s, was associated with the death of thousands of turkeys, ducklings and other domestic animals which had received a diet containing aflatoxin-contaminated groundnut meal. Many human fatalities occurred (Anon, 1993(a)) in India, in 1974, when unseasonal rains and a scarcity of food prompted the consumption of heavily aflatoxin-contaminated maize. Acute aflatoxicosis, also caused by the consumption of contaminated maize, caused fatalities in Kenya in 1982.

The chronic effects, caused by the consumption of low dietary levels (parts per billion) of the aflatoxins, on the health and productivity of domestic animals are well established. Reduced weight gain has been reported (Anon, 1989), for example, in cattle, pigs and poultry; reduced milk yield in cows; and reduced feed conversion in pigs and poultry. Low levels of aflatoxin have been associated with an increased susceptibility to disease in poultry, pigs and cattle. Vaccine failures have also been reported. If similar immunosuppressive effects are manifested in humans, it is possible that the aflatoxins (and other mycotoxins) could be significantly enhancing the incidence of human disease in developing countries.

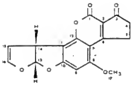
The Trichothecenes

The trichothecenes comprise a large group of mycotoxins, produced by a variety of *Fusarium* moulds. The current discussion will be limited to the two trichothecenes - T-2 toxin and deoxynivalenol - which occur naturally, in significant quantities, in cereal grains.

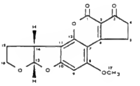
(i) T-2 toxin (Figure 2.2a)

F. sporotrichioides, the major producer of T-2 toxin, occurs mainly in temperate to cold areas and is associated with cereals which have been allowed to overwinter in the field (Anon, 1993(b)). T-2 toxin has been implicated in two outbreaks of acute human mycotoxicoses. The first occurred in Siberia (in the former USSR), during the Second World War, producing a disease known as 'alimentary toxic aleukia' (ATA). Thousands of people, who had been forced to eat grain which had overwintered in the field, were affected and entire villages were eliminated. The symptoms of ATA included fever, vomiting, acute inflammation of the alimentary tract, anaemia, circulatory failure and convulsions. Trichothecene poisoning also occurred in Kashmir, India, in 1987 and was attributed to the consumption of bread made from mouldy flour. The major symptom was abdominal pain together with inflammation of the throat, diarrhoea, bloody stools and vomiting. T-2 toxin was isolated from the flour together with other trichothecenes, namely deoxynivalenol, nivalenol and deoxynivalenol monoacetate (Figures 2.2b, 2.2c and 2.2d respectively).

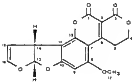
Figure 2.1. Chemical structures of the Aflatoxin group of mycotoxins.



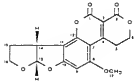
(a) Aflatoxin B_1



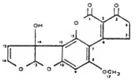
(b) Aflatoxin B_2



(c) Aflatoxin G_1



(d) Aflatoxin G_2



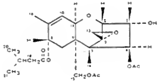
(e) Aflatoxin M_1

T-2 toxin has been implicated with the occurrence of haemorrhagic toxicoses (mouldy maize toxicoses) in farm animals. Oral lesions, severe oedema of the body cavity, neurotoxic effects and, finally, death have been reported in poultry, after the ingestion of feed contaminated with T-2.

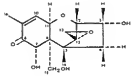
The most significant effect of T-2 toxin, and other trichothecenes, may be the immunosuppressive activity, which has been clearly demonstrated in experimental animals. The effect of T-2 toxin on the immune system is probably linked to the inhibitory effect of this toxin on the biosynthesis of macromolecules.

There is limited evidence that T-2 toxin may be carcinogenic in animals.

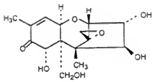
Figure 2.2. Chemical structures of the Trichothecene group of mycotoxins.



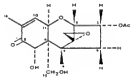
(a) T-2 toxin



(b) Deoxynivalenol



(c) Nivalenol



(d) Deoxynivalenol monoacetate

(ii) Deoxynivalenol (Figure 2.2b)

F. graminearum occurs worldwide and is the most important producer of deoxynivalenol (DON) (Anon, 1993(c)). The outbreaks of emetic (and feed refusal) syndromes in farm animals, produced by the presence of DON in their diets, has resulted in the trivial name, vomitoxin, being attributed to this mycotoxin.

DON is probably the most widely distributed *Fusarium* mycotoxin occurring in a variety of cereals, particularly maize and wheat. As stated above, DON has been implicated in a human mycotoxicosis, in India, in combination with T-2 toxin and other trichothecenes. Other outbreaks of acute human mycotoxicoses, caused by the ingestion of DON and involving large numbers of people, have occurred in rural Japan and China. The Chinese outbreak, in 1984-85, resulted from the ingestion of mouldy maize and wheat. The onset of symptoms occurred within five to thirty minutes and included nausea, vomiting, abdominal pain, diarrhoea, dizziness and headache. Another *F. graminearum* toxin, zearalenone (see below), was also isolated from the mouldy foodstuff.

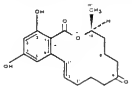
The immunosuppressive effect, of those concentrations of DON which are naturally ocurring, has been reported. There is inadequate evidence in humans and experimental animals, however, for the carcinogenicity of DON. DON is not transferred into milk, meat or eggs.

Zearalenone (Figure 2.3)

F. graminearum is also the most important producer of zearalenone, a widely-occurring mycotoxin which is responsible for many outbreaks of oestrogenic syndromes amongst farm animals (Marasas, 1991).

The occurrence of zearalenone in maize has been responsible for outbreaks of hyper-estrogenism in animals, particularly pigs, characterised by vulvar and mammary swelling, uterine hypertrophy and infertility.

Figure 2.3. Chemical structure of Zearalenone



As described above, zearalenone was isolated from mouldy cereals involved in an outbreak of acute human mycotoxicosis in China.

There is limited evidence in experimental animals, and inadequate evidence in humans, for the carcinogenicity of zearalenone. It is not transmitted from feed to milk to any significant extent.

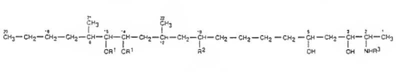
The Fumonisins (Figure 2.4)

The fumonisins are a group of mycotoxins which have been characterised comparatively recently (Anon, 1993(d). They are produced by *F. moniliforme* which occurs worldwide and is one of the most prevalent fungi associated with maize.

To date, only the fumonisins FB_1 and FB_2 appear to be toxicologically significant. The occurrence of FB_1 in cereals, primarily maize, has been associated with serious outbreaks of leukoencephalomalacia (LEM) in horses and pulmonary oedema in pigs. LEM is characterised by liquefactive necrotic lesions of the white matter of the cerebral hemispheres and has been reported in many countries, including the USA, Argentina, Brazil, Egypt, South Africa and China. FB_1 is also toxic to the central nervous system, liver, pancreas, kidney and lung in a number of animal species. FB_2 is hepatotoxic in rats.

The incidence of *F. moniliforme* in domestically-produced maize has been correlated with human oesophageal cancer rates in the Transkei, southern Africa and in China. The levels of fumonisins in domestically-produced maize have been reported as similar to those levels which produced LEM and hepatotoxicity in animals.

Figure 2.4. Chemical structures of the Fumonisin group of toxins.



Fumonisins

A_1. R^1 = $COCH_2CH(CO_2H)CH_2CO_2H$; R^2 = OH; R^3 = $C^{23}OC^{24}H_3$
A_2. R^1 = $COCH_2CH(CO_2H)CH_2CO_2H$; R^2 = H; R^3 = $COCH_3$
B_1. R^1 = $COCH_2CH(CO_2H)CH_2CO_2H$; R^2 = OH; R^3 = H
B_2. R^1 = $COCH_2CH(CO_2H)CH_2CO_2H$; R^2 = R^3 = H

Currently, there is inadequate evidence for the confirmation of the carcinogenicity of the fumonisins in humans. There is limited evidence, in animals, for the carcinogenicity of FB_1 but inadequate evidence for the carcinogenicity of FB_2. Data are not available for the transmission of these toxins into milk, meat and eggs.

Ochratoxin A (Figure 2.5)

Ochratoxin A is produced (Pitt and Leistner, 1991) by only one species of *Penicillium, P. verrucosum*, probably the major producer of this mycotoxin in cooler regions. Amongst the aspergilli, *Aspergillus ochraceus* is the main source of ochratoxin A.

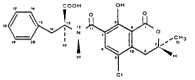
Ochratoxin A has been mainly reported in wheat and barley growing areas in temperate zones of the northern hemisphere. It does, however, occur in other commodities including maize, rice, peas, beans and cowpeas; developing country origins of ochratoxin A include Brazil,

Chile, Egypt, Senegal, Tunisia, India and Indonesia.

A correlation between human exposure to ochratoxin A and Balkan endemic nephropathy (a fatal, chronic renal disease occurring in limited areas of Bulgaria, the former Yugoslavia and Romania) has been suggested. A causative link, however, has yet to be confirmed.

Ochratoxin A produces renal toxicity, nephropathy and immunosuppression in several animal species.

Figure 2.5. Chemical structure of Ochratoxin A.



Although there is currently inadequate evidence in humans for the carcinogenicity of ochratoxin A, there is sufficient evidence in experimental animals. Ochratoxin A has been found in significant quantities in pig meat, as a result of its transfer from feedingstuffs.

THE INTERACTION OF MYCOTOXINS

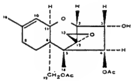
The complex ecology of mould growth and mycotoxin production can produce *mixtures* of mycotoxins in food and feed grains, particularly in cereals. The co-occurrence of mycotoxins can arise through a single mould producing more than one toxin and simultaneous contamination by two or more moulds, from the same or different species.

The co-occurrence of the *Fusarium graminearum* toxins deoxynivalenol and zearalenone with the *F. moniliforme* toxins fumonisin B_1 and B_2, for example, has been reported (Miller, 1991) in southern Africa. Other naturally occurring combinations of *Fusarium* mycotoxins include T-2/diacet-oxyscirpenol (DAS) (Figure 2.6a), deoxynivalenol/DAS and DAS/fusarenone (Figure 2.6b). Naturally occurring combinations of mycotoxins produced by more than one genus include aflatoxins/trichothecenes (Argentina), aflatoxins/zearalenone (Brazil, Indonesia), aflatoxins/ ochratoxin A and aflatoxins/cyclopiazonic acid (Figure 2.6c)/zearalenone (Indonesia), afla-toxins/fumonisins (USA). Given the worldwide distribution of the *Fusarium* moulds, the presence of combinations of *Fusarium* mycotoxins and aflatoxins in food and feeds of developing country origin should be expected.

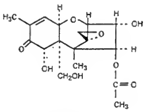
The co-occurrence of mycotoxins can affect both the level of mycotoxin production and the

toxicology of the contaminated grain. The presence of trichothecenes may increase the production of aflatoxin in stored grain, for example, whereas some naturally occurring combinations of *Fusarium* toxins are synergistic in laboratory animals. To date, little is known about this particularly important area of mycotoxicology. The significance of mycotoxins in human disease will become more clearly defined through the continued identification of biomarkers, present in blood and/or urine, which reflect the levels of recent dietary exposure to mycotoxins. Aflatoxin, covalently bound to albumin in peripheral blood, and the urinary aflatoxin B_1-guanine adduct have both been used, for example, to monitor aflatoxin ingestion.

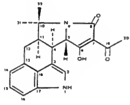
Figure 2.6. Chemical structures of Diacetoxyscirpenol, Fusarenone and Cyclopiazonic acid.



(a) Diacetoxyscirpenol



(b) Fusarenone X



(c) Cyclopiazonic acid

Studies using the aflatoxin-albumin adduct have demonstrated the significantly higher exposure that occurs in Gambia, Kenya and the Guangxi region of China, compared with Thailand and Europe. In Europe, the levels of biomarker were below the detection limit.

THE CONTROL OF MYCOTOXINS

Since the occurrence of mycotoxins is a consequence of biodeterioration, it follows that the mycotoxin problem is best addressed by controlling those agents - temperature, moisture and pests - which encourage spoilage.

The pre-harvest control of the agents of biodeterioration is somewhat compromised by Man's inability to control the climate! Both insufficient and excessive rainfall during critical phases of crop development can, for example, lead to mould contamination and mycotoxin production. The very substantial economic losses attributed to mycotoxins, on the North American continent, clearly illustrates the difficulties associated with the *prevention* of contamination, even in wealthy, developed nations.

Considerable effort has been expended on the development of crop strains which are resistant to mould growth and/or mycotoxin production. Breeding programmes have focused, for example, on the development of *Aspergillus*/aflatoxin resistant varieties of maize and groundnuts, with limited success. It has been suggested that wheat has three types of resistance to *Fusarium graminearum*; resistance to the initial infection, resistance to the spread of the infection and resistance to mycotoxin (deoxynivalenol) production. Attempts to exploit the resistance to mycotoxin production (through either the inhibition of synthesis or chemical degradation) may hold the most potential because of the limited number of genes which control this process.

The post-harvest handling of grains does, however, present many more opportunities for controlling mycotoxin production. Although many small farmers will not have access to artificial drying equipment, the importance of the utilisation of effective drying, and storage regimes cannot be overemphasised, and is covered extensively in later chapters. Drying to moisture levels which will ensure safe storage in tropical climates is especially important when grains are shipped from temperate to tropical climates.

However, despite the best efforts of the agricultural community, mycotoxins will continue to be present in a wide range of foods and feeds. Consequently, strategies are required for the *removal* of mycotoxins from grains. Currently, two approaches are utilised; namely, the identification and segregation of contaminated material and, secondly, the destruction (detoxification) of the mycotoxin(s).

The Segregation of Contaminated Grains

In the first instance, the identification and segregation of contaminated consigments is pursued through the implementation of *quality control* procedures by exporters, importers, processors and regulators. The consignment is accepted or rejected on the basis of the analysis of representative samples of the food or feed. Acceptable levels of mycotoxin contamination are specified by individual customers, commercial agreements and regulators. Currently, over 50 countries now regulate against the aflatoxins; 5 parts per billion (μg/kg) is the most common maximum acceptable level. Aflatoxin M_1 in dairy products is regulated in at least 14 countries, the tolerances for infant diets being 0.05-0.5ppb milk. Regulations exist for other mycotoxins including, for example, zearalenone (1mg/kg in grains; the former USSR), T-2 toxin (0.1mg/kg in grains; the former USSR) and ochratoxin A (1-50ppb food,

100-1000ppb feed; numerous countries). Guidelines, advisory levels and 'official tolerance levels' for deoxynivalenol also exist in some countries. The guideline in Canada, for example, refers to 2mg/kg in uncleaned soft wheat, 1mg/kg in infant foods and 1.2mg/kg in uncleaned staple foods calculated on the basis of flour or bran. In the USA, 4mg/kg is advised for wheat and wheat products used as animal feeds.

The mycotoxin content of grains can be further reduced during processing. Automatic colour sorting, often in combination with manual sorting, is widely used to segregate kernels of abnormal appearance (which are considered more likely to contain aflatoxin) during the processing of edible grade groundnuts. Mycotoxins can also be concentrated in various fractions produced during the milling process. Zearalenone and deoxynivalenol, for example, are reportedly concentrated in the bran fraction during the milling of cereals. It can be argued, however, that all fractions will contain mycotoxins if the original grain is heavily contaminated. Ochratoxin A appears to be reasonably stable to most food processes. In general, the stability of mycotoxins during processing will depend upon a number of factors including grain type, level of contamination, moisture content, temperature and other processing agents.

A further segregation process involves the removal of aflatoxin, from animal feeds, *after ingestion*. Here, mycotoxin binding agents - hydrated sodium calcium aluminosilicate, zeolite, bentonite, kaolin, spent canola oil bleaching clays - included in the diet formulation, reportedly remove aflatoxin, by adsorption from the gut.

The Detoxification of Mycotoxins

Ammonia, as both an anhydrous vapour and an aqueous solution, is the detoxification reagent which has attracted (Park *et al*, 1988) the widest interest and which has been exploited commercially, by the feed industry, for the destruction of aflatoxin. Commercial ammonia detoxification (ammoniation) facilities exist in the USA, Senegal, France and the UK, primarily for the treatment of groundnut cake and meal. In the USA, cottonseed products are treated in Arizona and California whilst maize is ammoniated in Georgia, Alabama and North Carolina. Commercial ammoniation involves the treatment of the feed, with ammonia, at elevated temperatures and pressures over a period of approximately 30 minutes. On-farm procedures, as practised with cottonseed in Arizona, involve spraying with aqueous ammonia followed by storage at ambient temperature, for approximately two weeks, in large silage bags.

The nature of the reaction products of the ammoniation of aflatoxin is still poorly understood. However, many studies have been performed, on both isolated ammoniation reaction products and treated feedingstuffs, in an attempt to define the toxicological implications of ammoniation. Very extensive feeding trials have been performed with a variety of animals including trout, rats, poultry, pigs and beef and dairy cattle. The effect of diets containing ammoniated feed has been determined by monitoring animal growth and organ weights together with haematological, histopathological and biochemical parameters. The results of these studies, combined with the practical experience of commercial detoxification processes, strongly indicate that the ammonia detoxification of aflatoxin is a safe process. However, the formal approval of the ammoniation process by the USA Food and Drug Administration is still awaited.

Commercial processes have not been developed for the detoxification of other mycotoxins.

SAMPLING AND ANALYSIS

The control of the mycotoxin problem comprises (a) the identification of the nature and extent of the problem (by the implementation of surveillance studies), (b) the introduction of improved handling procedures, which address the identified problems, and (c) the regular monitoring of foods and feeds as part of a quality control programme.

The operation of both surveillance studies and quality control programmes requires efficient sampling and analysis methods.

Since the distribution of aflatoxins (and, presumably, other mycotoxins) in grains is highly skewed, it is important that great care is taken to collect a representative sample (Coker and Jones, 1988). There is still considerable debate as to the appropriate size of such samples. In general, the sample size should increase with increasing particle size; samples of whole groundnuts, maize and rice, for example, should be of the order of 20, 10 and 5kg respectively. Samples of oilseed cake and meal should be approximately 10kg in weight. For whole grains, each sample should be composed of about 100 incremental samples, collected sytematically from throughout the batch, whereas samples of cake and meal require approximately 50 increments. It is important to remember that the collection of samples from the surface of a large, mature stack of grains will *only* reflect the quality of the outer layers. The mycotoxin content of the grain in the interior of the stack can only be monitored during the break-down of the stack. Needless to say, an incorrectly collected sample will invalidate the final analysis result.

The sampling of grain shipments, normally involving tens of thousands of tonnes of material, poses a particularly difficult sampling problem. Representative samples should be collected from carefully defined 500 tonne batches, using the methods described above. Potential sampling points include weighing towers, conveyor belts, and trucks and barges receiving the discharged material. The sampling of fast moving grain is a hazardous operation; automatic, on-line sampling equipment should be used wherever possible.

The reduction of the sample, for analysis, should also be performed so as to ensure the representative nature of the laboratory sample. It is imperative that the complete sample is comminuted prior to subdivision. Ideally, the comminution and subdivision of whole grains should be performed simultaneously, using a subsampling mill. Alternatively, the comminuted sample should be subdivided using a mechanical riffle. Manual coning and quartering procedures should only be used as a last resort.

Equipment available for the collection of representative samples is discussed in detail in Chapter 3.

High performance liquid chromatography (HPLC) has been used for the analysis of a wide range of mycotoxins including the aflatoxins, ochratoxin A, zearalenone, deoxynivalenol (DON) and the fumonisins. To date, high performance thin layer chromatography (HPTLC) has been applied mainly to the aflatoxins whereas gas liquid chromatography (GLC) has been

utilised for the quantification of DON, T-2 toxin and zearalenone. Enzyme-linked immunosorbent assays (ELISA) have also been applied to many mycotoxins including the aflatoxins, ochratoxin A, deoxynivalenol, T-2 toxin and zearalenone. Despite the utilisation of sophisticated, expensive HPLC, HPTLC, GLC and ELISA procedures, agreement between laboratories is invariably poor, when identical samples are analysed (Coker, 1984)!

Quality control programmes require simple, rapid, efficient analysis methods which can be handled by relatively unskilled operators (Coker, 1991). Recently developed rapid methods include those that utilise immunochemistry technology or selective adsorption agents. A rapid ELISA method for estimating aflatoxin in groundnuts, cottonseed, maize, rice and mixed feeds has been subjected to a collaborative study and recommended for First Action Approval by the Association of Official Analytical Chemists (AOAC). Solid phase ELISA kits have been developed for the aflatoxins, ochratoxin A, zearalenone and T-2 toxin in a variety of commodities. An 'immunodot' cup test, where the antibody is immobilised on a disk in the centre of a small plastic cup, has been approved by the AOAC as an Official First Action screen for aflatoxin in groundnuts, maize and cottonseed. Card tests have also been developed where the antibody is immobilised within a small indentation on a card similar in size to a credit card. Such tests have been developed for the aflatoxins, ochratoxin A, T-2 toxin and zearalenone in maize. The reported analysis (extraction, filtration and estimation) time for solid phase ELISA kits is 5-10 minutes. ELISA kits, however, are relatively expensive and suffer reduced shelf-lives at elevated temperatures.

Minicolumns (small glass columns) containing selective adsorption agents have been developed for aflatoxin/zearalenone (single test) and deoxynivalenol.
There is an urgent need for simple, robust, low-cost analysis methods, for the major mycotoxins, which can be routinely used in developing country laboratories.

CONCLUSIONS

The mycotoxins described in this chapter, as symptoms of biodeterioration, are acutely toxic, carcinogenic, immunosuppressive and oestrogenic; and have been the cause of serious human and/or animal diseases. The potential immunosuppressive role of mycotoxins in the aetiology of human disease is an especially important issue which requires further careful study. Every effort must be made to minimise the occurrence of mycotoxins in food and feed grains.

Undoubtedly, the implementation of improved handling and quality control procedures will have a significant effect on the incidence of mycotoxins in important foods and feeds throughout the world.

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CHAPTER 3

QUALITY AND GRADING OF GRAIN

INTRODUCTION

Most countries have developed national standards for their main grain crops. These have evolved to facilitate the movement of grain, providing both sellers and purchasers with guide-lines to support financial transactions, and ensuring that quality will meet up with end-use requirements.

Where trading involves direct choice and price negotiation in front of the commodity, grading standards are rarely employed; quality is assessed visually and is influenced by end-use, and the price is determined more by local rather than national factors. For transactions that involve the movement of large volumes of grain over long distances, the buyer may never meet the seller or be able to examine the whole consignment. The standard will provide an unambiguous description of the quality of the consignment and assist in the formation of a legally-binding contract. Standards can also be seen to protect consumers rights through setting limits to the amount of unsuitable or noxious material.

The use of grading standards can send a clear indication of quality requirements to both producer and end-user. Although some countries have sought to support small farmers through purchase of all grain at the same price without regard to quality: under these circumstances grading standards cease to be operative by default. This may stimulate productivity but creates problems for end-users such as millers who require uniformity and consistency in quality to ensure efficient and cost-effective processing.

Whilst establishment of standards can set the guide-lines and rules for sale and purchase of grains, there has to be an institutional framework for their implementation. This is much easier to establish at centres of aggregation of grain e.g. ports, parastatal grain depots, than in the more diffuse rural areas and markets, where control and supervision of regulations is difficult.

Notwithstanding these problems, the establishment of quality and grading standards for producers and users can be beneficial in the following ways:

* Graded grains are likely to be more equably priced than non-standardised grains. This will bring stability not only to market prices but also to the quality offered.

* Prices quoted against a recognised grade assist producers and traders to market their products. This will also benefit net consumers of grain in more stable prices with assured quality.

* Greater conformity in quality through standardisation will provide the millers, bakers and other processors with the consistency necessary for optimum performance.

* Standards reveal clear variations in quality and indicate the opportunities for improvement and the potential rewards to be obtained.

* The sanitary hazards associated with the inter-country movement of grain can be reduced if clearly-defined standards are enforced, particularly in relation to the prevention of spread of serious storage pests like the Larger Grain Borer.

However, the use of standards can have its disadvantages, namely:

* National standards may reflect local end-uses and hinder export to areas that have differing requirements. Whilst restricting opportunities for commercial trade, this can also be detrimental for regional food security. The stimulation of regional trade would require inter-country conformity in export standards. These may have to be more stringent in relation to physical conditions such as moisture content, defective grains and insect infestation, than that for national use.

* The establishment of standards and the quality assurance practices to regulate and enforce them carries costs which have to be carefully considered to avoid imposing unnecessary expense for little improvement in quality.

QUALITY CHARACTERISTICS OF GRAINS

Consumers have become accustomed over the years to demanding grain with particular qualities. Where consumers are close to the source of the grain, e.g. in local markets, their own preferences and the laws of supply and demand will control the quality of the grain. However, where grain is traded over large distances, particularly internationally, the consumer will have no direct influence over quality, and regulatory standards must be established and imposed to protect consumer rights. Therefore criteria of grain quality must be established and accepted by all parties in the grain trade. The criteria assigned to grain are the intrinsic varietal qualities and those which are environment- or process-induced. The more important quality criteria as they relate to grading of grain are described in the following sections.

Intrinsic Qualities

(i) Colour

Cereal grains are pigmented and range through the colour spectrum from very light tan or almost white, to black. Where extractive milling is required, highly-pigmented varieties may give low yields of white flour.

(ii) Composition

Composition, e.g. protein, carbohydrate, lipids and their breakdown products, qualitatively influences product acceptability, by affecting texture and taste. Quality changes evolve slowly in stored grain and more rapidly in milled or processed intermediary products.

Some grain components, for example husk, are inedible and quantitatively influence product yield and gross nutrient available to the consumer.

(iii) Bulk Density

Each type or variety of grain when in optimum health, fully mature, etc, has a characteristic bulk density. This is defined as the weight per standard volume, measured in a standard manner. The same characteristic is variously known as 'test weight', 'bushel weight' or 'specific weight'. For details of how bulk density is measured see page 62.

If the bulk density varies the trend is usually downwards and indicative of reduced overall quality of the grain. Hence it is often measured in the grain trade. Factors which commonly affect bulk density are insect infestation, excessive foreign matter and high percentage moisture content. In wheat, bulk density is considered to be a reasonable indicator of milling yield.

Bulk density should not be confused with 'specific volume' as defined in the context of Chapter 6 of this bulletin. The terms are related, but the distinction is necessary because it is an established fact that the 'bulk density' of grain increases when it is stored in large quantities, bag or bulk, due to compaction.

(iv) Odour, aroma

Most grain types, when fresh, have a distinctive natural odour or aroma. This is generally accepted as an indicator of good quality, although some people prefer grain which smells 'old' or even fermented.

As with most natural produce, some grain varieties are better-liked than others because of their odour. Certain cultivars of rice, for example, possess aromatic qualities which are considered desirable by some consumers.

See also mixed variety.

(v) Size, shape

Rice, as a whole-grain food, is classified by size (length) and shape (length:breadth ratio). Other grains also have size considered in their specification. In general a small range in size assists with processing and handling.

Induced Qualities

(i) Age

During the post-harvest phase, grain undergoes complex biochemical changes termed 'aging'. Changes to carbohydrate, lipids and protein fractions result in, for example, firming of texture in rice on cooking, and increased gas-retention capability in wheat flour. For most consumers, the effects of these changes are considered to be desirable. When plotting consumer acceptability of a grain product against its age since harvesting, generally it is considered to be maturing during the upward curve of the graph, and deteriorates only when the curve changes direction downwards.

(ii) Broken grain

Grain is marketed normally in whole grain form and is considered to be of inferior quality if broken. Breakage may occur from fissures as a result of excessive drying/weathering conditions in the field or during handling. Breakage reduces quality by reducing acceptability and by increasing susceptibility to infestation during storage. This affects milling yield by contributing to weight loss.

(iii) Chalky or immature grain

Empty grains result from sterility and pre-harvest infections and insect attack. Immature grain content is affected by time of harvest. In rice, immature grains are greenish in colour. Thin white (usually opaque) grains are caused by incomplete grain filling and may result from pests or disease. Chalkiness is caused by incompletely filled starchy endosperm which disrupts light transmission, causing opaque regions. In most cereals, chalky areas have lower mechanical strength on crush tests and may break during handling. The broken portion is more easily invaded by certain storage pests.

(iv) Foreign matter

Dilution of the prime product by foreign matter reduces the value, and also may affect handling and processing. Foreign matter may be subclassified as:

animal origin - insects and their products, rodent excreta, etc;
vegetable origin - straw, weeds, seeds, dust, micro-organisms/toxins;
mineral origin - stones, mud, dust, glass, metals, oil products, pesticide residues.

Elements from all three subclasses may render the grain unfit for consumption. Potentially the greatest threat to health probably is from micro-contamination with the bacterial products of poor sanitation, and with toxins and chemical pesticide residues.

(v) Infested, infected grain

Grain mass, and therefore yield, is reduced by infestation. Contamination not only has direct food hygiene implications but also indirect ones, as invading micro-organisms may produce toxins under certain conditions which may lead to acute or chronic illness.

(vi) Mixed varieties

A mixture is an indication of poor pre- and post-harvest management and supervision, e.g. seed selection, lot segregation and treatment, contamination, etc. Grains differing in size and other characteristics affect processing potential. Whilst preference for a particular variety may be influential nationally or regionally, internationally-traded grain is recognised usually by grain type rather than by variety e.g. yellow or white maize. Exceptions do occur, e.g. basmati rice, (see odour, aroma).

(vii) Moisture content

Moisture content (mc) of grain plays a crucial role in post-harvest processing and is associated with most of the induced characteristics. Water vapour will diffuse throughout a bulk of grain and the mc will tend to equalise. 'Hot spots' may occur at a site of increased respiration (caused by sprouting, infestation or microbial activity), and condensation may occur on cold grain or containers.

GRAIN STANDARDS

The term 'standard' used in the present context refers to the measures that serve as a basis for making comparisons or judging the accuracy of unknown samples. Three types of standard will be covered in this chapter:

- standard *specification* which define and specify a subject,
- standard *test method* by which a specification is tested,
- *grading* standard which allow a subject to be classified into more than one category.

Standards are established for a variety of purposes but mainly: a) for produce grading in agricultural marketing, or, increasingly, b) for the protection of consumers. The requirements of the two groups are not necessarily compatible.

Standard Specification for Grain

There are at least 330 specifications for cereals and cereal products at national and international level (over 50 countries or regions) of which at least 12 are applicable globally. Standard specifications provide criteria to characterize the nature of a commodity, usually on a pass or fail basis.

Most countries have a national standards institution which may issue specifications for commodities as well as methods of testing. Many countries adopt or modify international standards, e.g. International Organization for Standardization (ISO) standards, into their national system. Another source is the Codex Alimentarius Commission (Codex) which operates a committee to formulate standards on cereals, pulses and legumes.

Tables 3.1 and 3.2 show examples of trading-bloc and national standards, and Tables 3.3 and 3.4, examples of international standards.

Table 3.3 shows the ISO standard specification for wheat: a sample is judged against the standard, and may be referred to as wheat if it passes all the criteria listed.

One notable feature of the standards in Tables 3.1 to 3.4 is the difference in tolerance of mc. Both of the quoted international standards allow 15.5%, whereas the European Community (EC) and Ethiopian standards have lower values, 14.5 and 14.0% respectively.

In the cited examples, not only do we have the potential for mis-interpretation but also, more seriously, the basis for deterioration of the product. For example, take the case of maize with 15.0% mc loaded into a ship in northern latitudes at 4°C. Calculated from data presented by Foster (1982), such grain would have an inter-grain equilibrium relative humidity (ERH) of approximately 65% which is normally regarded as safe. However, if the grain is unloaded in a tropical country with an ambient temperature of 32°C, its inter-grain ERH becomes 75% - too high for safe storage.

Boxall and Gough (1992a and b) monitored shipments of food-aid maize grain from north America to southern Africa. They reported that heating and mould-damage took place when the grain was stacked at port of discharge, and confirmed that the standard mc of 15.5% at loading was too high for the conditions at the destination. A second shipment of grain dried specifically to approximately 14.5% mc suffered damage as well. In comparison, an intra-African importation with 12.2% mc did not suffer heating or deterioration on storage. Studies are continuing at NRI on the importance of integrating quality standards between suppliers and consumers.

The problems associated with moisture content may be harmful to international trade in grain and need to be addressed adequately by the standardisation institutions. ISO 7979 (Table 3.3) goes some way towards this by acknowledging the principle of destination-specific mc, though without defining appropriate action.

Standard Test Methods

There are at least 420 standard test methods for cereals and cereal products at national and international level (over 50 countries or regions) of which at least 75 are applicable globally.

As with the specification of cereals, many countries modify or adopt international standards, e.g. International Organization for Standardization (ISO) standards, into their national system. Another important organisation, particularly for the development of testing methods, is the International Association for Cereal Science and Technology (ICC). Other organisations issuing standard test methods include the Association of Official Analytical Chemists (AOAC) and the American Association of Cereal Chemists (AACC).

Table 3.1. European Community Intervention Regulations on Minimum Quality Standards.

	Durum Wheat	Common Wheat	Rye	Barley	Maize	Sorghum
A. Maximum moisture content %	14.5	14.5	14.5	14.5	14.5	14.5
B. Maximum percentage of matter which is not basic cereal of unimpaired quality % of which:	12	12	12	12	12	12
1. broken grains %	6	5	5	5	10	10
2. impurities consisting of grains (other than indicated at (3) % of which:	5	7	5	12	5	5
(a) shrivelled grains %						
(b) other cereals %	3			5		
(c) grains damaged by pests %						
(d) grains in which the germ is discoloured %						
(e) grains overheated during drying %	0.5	0.5	3	3	3	3
3. mottled grains and/or grains affected with fusariosis % of which:	5					
- grains affected with fusariosis %	1.5					
4. sprouted grains %	4	6	6	6	6	6
5. miscellaneous impurities (Schwarzbesatz) % of which:	3	3	3	3	3	3
(a) extraneous seeds: - noxious %	0.1	0.1	0.1	0.1	0.1	0.1
- other %						
(b) damaged grains: - grains damaged by spontaneous heating or too extreme heating during drying %	0.05	0.05				
- other %						
(c) extraneous matter %						
(d) husks %						
(e) ergot %	0.05	0.05	0.05			
(f) decayed grains %						
(g) dead insects and fragments of insects %						
C. Maximum percentage of wholly or partially mitadine grains %	40					
D. Maximum tannin content %*						1
E. Minimum specific weight (kg/hl)	78	72	68	62		
F. Protein content %*	11.5					
G. Hagberg falling number	220	220				
H. Zeleny index		20				

* Percentage calculated on the dry matter.

Source: Commission Regulation (EEC) No 689/92 of 19 March 1992

Table 3.2. Ethiopia - Grain Grading Standards.

Standard reference:	Wheat B.B1.210	Maize B.B1.202	Barley B.B1.203	Sorghum B.B1.204
Moisture content (% max.)	14	14	14	14
Ergot infection (% max.)	0.3		0.3	
Smut infection (% max.)	0.2		0.2	0.2
Weevils or other insects injurious to stored grain (% max.)	0	0	0	0
Mould or mouldy/unnatural odours (% max.)	0	0	0	0
Stained, weathered or badly discoloured grains (% max.)			0	
Requirements for grade 1 of each grain*:				
Minimum test mass (kg/hl)	78	56	60	49
Damaged, shrunken and weevilled kernels (% max.)	2.3	5.5	2.5	5.5
Foreign matter (% max.)	2.2	1.5	2.0	1.5
Noxious weed seeds (% max.)	0.5		0.5	
Contrasting classes (% max.)	1.0	1.0	1.0	1.0
	6.0	8.0	6.0	8.0

* Ethiopian Standards define more than one grade

Source: Ethiopian Authority for Standardisation

Table 3.3. International Standard - Wheat - Specification ISO 7970: 1989

Maximum tolerances (% m/m):	
Foreign or deteriorated odour, additives, toxic substances	0
Pesticide residues, other contaminants	National limit or Codex limit
Living insects	0
Moisture content	15.5*
Bulk density, minimum (kg/hl)	70
Damaged grain	15
of which:	
Broken grain	7
Shrivelled grain	8
Unsound grain	1
Grain attacked by pests	2
Other cereals	3
Extraneous matter	2
Inorganic material	0.5
Harmful and/or toxic seeds, bunted grains and ergot	0.5
Ergot	0.05
Falling number, minimum	160

* Lower moisture contents are required for certain destinations, in relation to the climate, and duration of transport and of storage. For further information, see ISO 6322, parts 1, 2 and 3.

Source: International Organisation for Standardisation

Table 3.4. Codex Standard for Maize (Corn) Codex Stan 153-1985

Maximum tolerances (% m/m):	
Abnormal or foreign odour	0
Moisture content	15.5
Blemished grain	7
of which:	
diseased grain	0.5
Broken kernels	6
Other grains	2
Foreign matter	2
of which:	
inorganic matter	0.5
Filth	0.1
Toxic or noxious seed, heavy metals, microorganisms or poisonous or deleterious substances	free from amounts hazardous to health

Source: Codex Alimentarius Commission

GRAIN TRADE

Table 3.5 shows the world production and trade figures for grain for the year 1990. Total grain movement across national borders was approximately 225 million tonnes, representing some 12% of grain production. This large trade in grain highlights the need for both national and international standards to ensure uniformity in quality and quantity of grain.

Table 3.5. World Grain Statistics.

Year: 1990	Production '000 t	Imports '000 t	Exports '000 t
Africa	87751	27785	2725
N + C America	402095	16270	115770
S America	68503	8517	11227
Asia	859650	98878	15808
Europe	283238	40078	62527
Oceania	24587	787	14802
USSR	228854	32862	1641
World	1954678	225177	224500

Source: FAO Trade and Production Year-book

National requirements

It could be argued that a commodity standard should be country-specific, containing factors such as percentage brokens, foreign matter, moisture content that reflect the types of end-use, be it for commercial or domestic purposes. Government policy on the liberalization of the grain market may reduce the significance of domestic quality standards, and it is up to the buyer and seller to decide on quality and price. Although a government may retain the use of standards under particular circumstances e.g. for national food reserves, where quality control will be important.

Regional requirements

End-usage, and hence standards, may vary from one country to the next. Where standards vary considerably between countries, the movement of grain may be hindered. A country may have a single standard that covers both internal and external grain movement. This may not facilitate the trade of a commodity between countries, particularly if the standard permits a greater degree of defective grains than its potential trading partner.

Regional food security may be impaired if the quality of the commodity is not acceptable by some of the countries in the region. Therefore a quality grading standard, acceptable by all users would be necessary for a commodity stored as part of a regional food security programme.

International trade

International trade of grain may be possible without a standard, if buyer and seller are aware of each others' requirements. However when country-specific information and requirements are not known, a standard will provide the guide-lines that ensure the maintenance of quality, and safeguard consumers' rights. The need for detailed standards may be lessened if a country adopts the "fair average quality" system of assessing quality and price of grain consignments (see below).

STANDARD GRADING OF GRAIN QUALITY

It was noted above that there is more than one reason to establish standards. Consumer-orientated standards tend to specify the nature of a commodity on a pass or fail basis, particularly in relation to wholesomeness or fitness for consumption. Producer or market-orientated standards tend to grade grain into one of several classes based usually on inherent quality and projected market value.

Fair average quality (FAQ)

The selling and buying of produce on a Fair Average Quality (FAQ) basis, as practised by many national and international marketing agencies, is essentially subjective. Normally, samples from different parts of the available stock of produce offered for sale (which may be scattered on farms or in warehouses throughout the producing area) and submit them under seal to independent assessors (public analysts or the like) for appraisal. After

examining the samples by sight, smell, taste and (perhaps) touch, the assessors will eslect those samples which they consider representative of the bulk of the samples, mix them together and reduce the lot to a single reference sample which is declared to represent the Fair Average Quality of the seller's stock. Parts of this sample may be used for certain objective tests, e.g. determination of percentage moisture content, oil content, free fatty acid content, or bulk density, if requested by the sellers, buyers or both. In any event, the main part of the reference sample is retained by an independent agency such as the Grains and Feeds Trade Association (GAFTA) for a specified period, during which any transactions involving the produce should be completed. If there is a dispute over quality the independent agency can be referred to for arbitration, and the reference sample may be used as evidence.

It is important to appreciate that the results of the FAQ assessment relate only to the crop which has been sampled, and only for the period agreed upon between the sellers and buyers. If consecutive FAQ same from the same crop, or FAQ samples from the same growing area in consecutive years, or FAQ samples of the same commodity grown concurrently in different areas are compared objectively significant differences in quality may be revealed. Thus FAQ has a loose definition, and can only be applied when fairly wide variations in quality can be tolerated.

The main advantage of FAQ is, of course, that it enables producers to dispose of most of their crop with the minimum of trouble and expense. At the same time the buyer can expect to gain by paying only a moderate price for the crop, although he does run the risk of having to bear the cost of additional processing is quality is some way short of optimal.

Grain specification

Table 3.1 includes the EC minimum quality intervention standard for wheat. There is a series of Articles in the Commission Regulations, in which relaxations of these grading standards are noted at individual national level. The Articles also allow a deduction or premium to be made according to changes in individual characteristics, e.g. increased prices paid for lower mc and grain defects, and for higher specific weights (bulk densities).

In comparison, ISO 7970 allows lighter grain with higher mc, higher damaged grain, but lower extraneous matter. 'Wheat' as specified must contain a low amount of non-wheat matter, but tolerates higher levels of grain defects, whereas 'wheat' as graded incorporates an element of processing value for the purchaser by rewarding desirable properties.

Conway *et al* (1992) studied quality/value relationships in milled rice. In a system with well-organised grain quality inspection, they found that qualities apparent at acceptance were only partially reflected in the wholesale price. More cryptic qualities, manifested as change in 'colour' during storage, formed the greater part of the valuation. It is a measure of the success of the application of the acceptance standard that these qualities did not feature largely in the valuation; also, of the valuers' reliance on, or habituation to, the standard. It shows that the acceptance system should not be relaxed, rather that it may need supplementing to cover the newly-identified qualities.

SAMPLING, EQUIPMENT AND METHODS

Table 3.6 shows a number of standard test methods dedicated to sampling. There are at least 30 methods, of which 5 or more are applicable internationally. The remainder are national or regional standards.

The need for sampling

Batches of grain are rarely uniform in quality even when regarded as acceptable. Pests usually occur non-randomly in stored grain. Consequently the only sure way of obtaining complete and accurate information about the grain is to carry out a total examination. This may be possible if the quantity to be examined is small, but is usually neither practical nor economical when a large quantity is involved. The choice is either not to examine the consignment at all or to take samples to obtain some information, acknowledging that anything less than a total examination is bound to affect the accuracy of the results.

Principles of representative sampling

The results of sample analyses can be expressed in precise terms. However, precise analytical results may be of little practical value, and may be misleading if the samples are obtained without taking into account the non-random or aggregated distributions of foreign matter, damaged grains, insects, etc.

Certain principles of representative sampling must be observed:

* The consignment should be divided into primary units of equal size or status, which may be sampled. For bagged grain, each bag may be regarded as a primary unit. For bulk grain, the primary unit may be expressed in terms of **weight**, if the grain is being moved, or **volume**, when it is static - as in a truck or bin.

* All primary units should have an equal opportunity of being sampled. This is possible only during the construction or dismantling of a stack, the loading or off-loading of a truck, or when bulk grain is being moved.

* The method should select, without bias, a representative number of primary units from the consignment.

Many countries adopt the recommendations of ISO 950 "Cereals - Sampling (as grain)". Its recommendation for selecting a proportion of bags is shown in Table 3.7, and for grain in road and rail trucks in Figure 3.1.

Working sample size

In practice, it is necessary to compromise between what is theoretically attainable and the natural desire to obtain results of analyses as quickly as possible. Providing the associated margins of error are recognised and accepted, it is generally suggested that working samples of between 500 and 1000 grains should be used for the determination of common defects such

Table 3.6. National and International Standards - Sampling.

COUNTRY	SHORT TITLE	SOURCE	REFERENCE	DATE
Bolivia	Sampling	DGNT	DGNT N.B.-10.7-009	1973
Bulgaria	Sampling, handling	BDS	BDS 600	1980
Bulgaria	Sampling, procedures	BDS	BDS 3642	1987
China	Sampling	CSBS	GB 5491	1985
Colombia	Sampling	ICONTEC	ICONTEC 271	1978
Cuba	Sampling	CEN	NC 86-02	1981
C. America	Sampling	ICAITI	ICAITI 34 051	1978
Denmark	Sampling	DS	DS/ISO 950	1980
Ethiopia	Sampling of grain	ESI	B.B8.200	1974
France	Sampling	AFNOR	NF V 03-700	1967
Germany	Cereals and pulses, sampling as meals	TGL	TGL 32 692/01	1987
Germany	Cereals and pulses, sample preparation	TGL	TGL 32 692/01	1977
Global	Cereals and cereal products: sampling	ICC	ICC 101	1960
Global	Cereals: sampling milled products	ISO	ISO 2170	1980
Global	Grain: mechanical sampling	ICC	ICC 120	1974
Global	Sampling (as grain)	ISO	ISO 950	1980
Global	Sampling (automatic)	ISO	ISO 6644	1981
India	Cereals and pulses	ISI	IS 5315	1978
India	Sampling	ISI	IS 2814	1978
Kenya	Sampling (as grain)	KBS	KS 01-60	1978
Poland	Sampling	PKNM	PN-72/A-74001	1972
Portugal	Sampling (as grain)	NP	NP 512	1982
Portugal	Sampling of crushed products	NP	NP 1201	1983
Portugal	Sampling of milling products	NP	NP 1201	1976
Saudia	Cereals & legumes, babyfoods, sampling	SSA	SSA 134	1979
Spain	Sampling	INRN	UNE 34-068:73.1	1973
Sri Lanka	Cereals: sampling ground products	SLSI	SLS 190	1973
Sri Lanka	Sampling	SLSI	SLS 528	1981
UK	Sampling: grain	BSI	BS 4510	1980
UK	Sampling: milled products	BSI	BS 5333	1981
UK	Sampling: automatic	BSI	BS 6298	1982
USA	Sampling	AACC	Method 64	1962

Source: Natural Resources Institute.

as insect damage, broken grains and discoloured grains. Equivalent minimum working sample weights are:

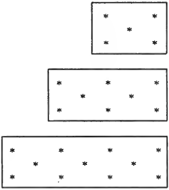
Maize (small grain)	200g
Maize (large grain)	250g
Sorghum	25g
Black-eyed cowpeas	150g
Wheat	25g
Bulrush millet	10g
Paddy	15g

Samples of these sizes can be analysed in 10 to 20 minutes, depending upon the skill of the inspector and available equipment.

Table 3.7. Selection of Bags for Sampling.

Number of bags in consignment	Number of bags to be sampled
Up to 10	Every bag
11 to 100	10, drawn at random
More than 100	Square root (approximately) of the total number of bags drawn at random according to a suitable scheme.

Figure 3.1. Sampling Points in Bulk Grain Carriers.



Truck containing up to 15 tonnes: five sampling points (middle and approximately 50 cm from sides).

Truck containing 15 to 30 tonnes: eight sampling points.

Truck containing 30 to 50 tonnes: eleven sampling points.

Source: International Standard ISO 950

In the USA, minimum working sample weights of 250g and 1000g are required for the determination of ergot and garlic respectively in wheat, while 250g samples are recommended for the determination of smut in both wheat and sorghum. Such 10 to 40 fold increases on the basic working sample weight illustrate what is meant by 'large' and 'small' sample sizes.

There is a need for sampling awareness when dealing with grain contaminated with mycotoxins. As analytical techniques improve, so detectable and tolerance levels are being lowered. To emphasise the link between the standard test method and specification, Jewers *et al.* (1989) conclude, "When aflatoxin levels are controlled by legislation it is important that sampling procedures and sample sizes are specified."

For the determination of foreign matter and live infestation, samples should be as large as possible. If bagged grain is being tested, the best results are obtained by passing the entire contents of sample bags over a suitable sieve.

Equipment for obtaining primary samples from bagged grain

(i) Simple bag sampling spears

These are the most commonly-used instruments for taking samples from bags, being relatively cheap, simple and quick. The main variations in design are illustrated in Figure 3.2. Generally, sampling spears having a maximum external diameter of about 12mm are designed for small grains such as wheat, while 25mm diameter spears are suitable for larger grains. To obtain a good cross-sectional sample the spear should be 40 to 45cm in length.

The tapered type of sampling spear penetrates bags easily. However, it takes unequal portions of grain from along the line of penetration, which could lead to distorted assessments of grain quality. More even sampling is achieved with the cylindrical type of sampling spear.

The main disadvantage of obtaining samples with these instruments is that it does not conform to the basic principles of representative sampling. If foreign matter or defective grain happens to be very unevenly distributed in the bag, the haphazard nature of spear sampling could lead to a distorted quality assessment (Figure 3.3).

(ii) Double-tube sampling spears

These spears (Figure 3.2D) comprise two metal tubes, one fitting closely inside the other and each with several common slots. Spears may vary in length from 45cm to 3.5m, and in width from 12mm to 50mm. Turning the inner tube through 180° opens or closes the intake apertures, and so collects grain from a transverse section of the bag.

Double-tube sampling spears are designed primarily for obtaining samples from vertical lines of penetration in bulk grain, although small versions may be used for sampling bagged grain. They are superior in many ways to the simple bag sampling spear, but are still instruments of haphazard rather than representative sampling.

(iii) The Produce-Flow sampler

This sampler (Figure 3.4) was designed at the Tropical Products Institute, now a part of NRI, as a representative sampling device for bagged grain. Grain is tipped into the hopper and falls through onto a cone, which is positioned to ensure that the flow is evenly distributed. Some of the grain is trapped by four vents arranged equidistantly around the base of the cone, and directed via a separate spout into a sample collector. The size of the sample depends upon the dimensions of the vents, which are interchangeable. Sampling of a 100kg bag of grain is complete within 20 seconds of starting the flow.

Equipment for obtaining primary samples from bulk grain

Bulk grain is sampled either when it is static, i.e. when it is contained in a truck, barge or storage bin, or when it is on the move, i.e. when it is being discharged through a spout or on a conveyor belt. A wide range of sampling equipment has been developed to meet the special requirements of these various situations, some for small-scale operations and other items for situations where grain is handled in very large quantities.

(i) Equipment for sampling static bulk grain

Double-tube sampling spears (see also above)

Spears 1.8m long and 3.5cm outer diameter are commonly used, but longer 3.7m double-tube spears are available for sampling grain in exceptionally deep trucks and barges.

The sampling spear should always be inserted into bulk grain at a slight angle from the vertical, with the slots facing upward. The slots must be opened only when the spear has reached the sampling position, and must be closed before it is removed.

Manually-operated deep bin probes

The simplest probe of this type consists of a hollow spear head, which serves as a sample cup, with a spring-loaded cap attached to a metal or wooden rod about 1 metre long. Extension rods are attached to increase the depth of penetration. When the sampling point has been reached a slight upward pull on the rod lifts the cap of the spear head, allowing grain to fill the cup. The probe is then withdrawn completely and the sample removed. A single probe yields up to 300g of sample material.

The deep bin fin-probe consists of a double-tube sampler with a set of extension rods. When the sampling position is reached a twist of the extension rod opens the sample intakes. This action is facilitated by the fin which prevents the outer tube from turning. A reverse twist closes the sample intakes before the probe is withdrawn from the grain. Up to 600g of sample representing a 1.5m long vertical 'cut' may be obtained.

A considerable amount of physical effort is required to push any of these probes into grain. None can be expected to penetrate more than approximately 5 metres.

Figure 3.2. Typical Spears for sampling Bagged Grain.

A: Closed spear for sampling large grains such as maize

B: Closed spear for sampling small grains such as wheat

C: Open spear

D: Double-tube spear

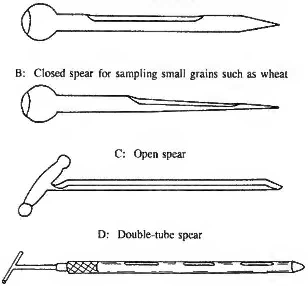
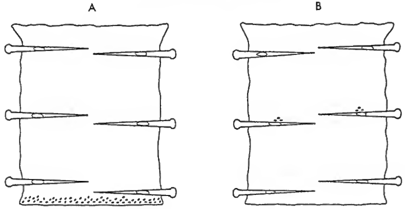


Figure 3.3. Inadequacy of Spear Sampling.
Black dots represent grain defects



A Large populations can be under-estimated. B Small populations can be over-estimated

Figure 3.4. Vertical section of Produce-flow Sampler.

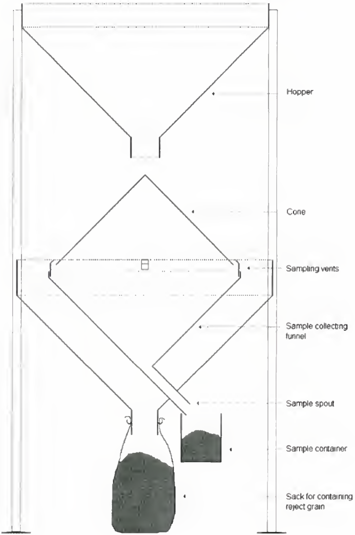
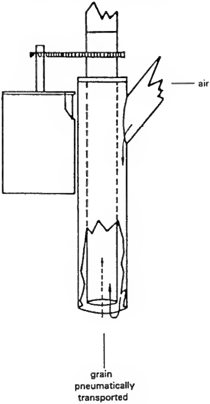


Figure 3.5: Pneumatic Sampler.



Pneumatic grain samplers

Pneumatic grain samplers overcome the main disadvantages of manual operation by using powered-suction to penetrate the static bulk of grain, and by taking a continuous sample. They are quicker to operate than manual samplers, and can be used easily to obtain samples from the sides and floors of bulk grain containers. An example is shown in Figure 3.5.

Auger-type sampler

The sampler consists of a tube approximately 1.4m long and 5cm wide, open at the bottom end and housing a motor-powered auger. Grain lifted by the screw is collected in a bag at the outlet spout. It is necessary to insert the device into the grain at an angle in order to obtain sample material. There are no extension pieces which would permit sampling deeper than the half metre or so the sampler penetrates. The sampler is therefore of limited usefulness.

(ii) Equipment for sampling moving grain.

The Pelican sampler

The Pelican sampler (Figure 3.6A) consists of a cowhide pouch attached to a metal frame at the end of a hardwood or tubular metal handle. It is used to obtain samples from free-falling grain, e.g. from a spout discharge to the hold of a ship.

If the spout is sloping, the components of the grain stream are likely to be stratified. It is important, therefore, to cut the sampler through the stream from one side to the other in a single motion to obtain a good sample.

The force behind a stream of grain may be very great. It is essential to observe appropriate safety measures when sampling in this manner.

The Ellis Cup sampler

This is a hand-held scoop (Figure 3.6B), designed for obtaining small samples from bulk grain on moving conveyor belts. When properly used, the cup will obtain a vertical section

of the flowing grain at the point where it is inserted into the stream. Samples taken in this way are used for making spot checks on the condition of grain and are not intended as substitutes for representative samples obtained elsewhere in the system.

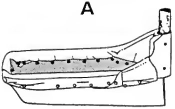
Sampling with the Ellis cup is hazardous. Extra safety precautions are necessary, as with the Pelican sampler.

Limpet-type sampler

This type of sampler is clamped or bolted to the outside of the delivery spout. A tube is inserted through a hole drilled into the spout wall. The tube usually is open at both ends and has an inlet slot in the upper side projecting into the grain stream. Sampled material is removed either by means of a motorised worm screw, or a plunger operated by compressed air. Worm screw extractors can be made to operate continuously or at intervals. Plunger sample extractors remove samples of fixed size at intervals.

The limpet sampler is capable only of extracting material from part of a grain stream. Figure 3.7 shows the auger principle in operation. If there is any appreciable stratification of material in the stream, samples cannot be regarded as representative.

A



B

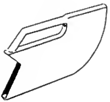


Figure 3.6: Manual sampling of moving grain. A Pelican sampler. B Ellis Cup sampler.

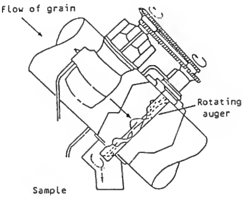


Figure 3.7 (left). Limpet sampler.

The diverter-type sampler

The diverter-type sampler is probably the best device yet invented for obtaining representative samples from bulk grain. The sampler (Figure 3.8) is designed to take a complete cross-section of a stream of grain, by means of a powered diverter head which takes a cut through the stream, on a preset schedule. During periods of inactivity the aperture of the diverter head is sealed to prevent it collecting dust.

Grain extracted from the main stream by the sampler may be fed directly into a secondary sampler, which reduces the sample to a manageable size before it is delivered via spouting to the grain inspection laboratory. Figure 3.8 shows the principle of operation.

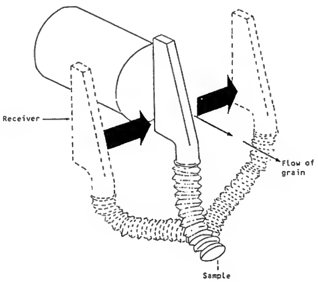


Figure 3.8. Principle of operation of the Diverter sampler.

QUALITY DETERMINATION, EQUIPMENT AND METHODS

The term 'quality' has different meanings for those who are concerned with the handling, storage, processing and utilisation of grain, even though all will be looking for grain of 'good quality'. For example, grain-handling agencies will want dry, insect-free, undamaged grain which will store well; millers will want a grain which will yield a high percentage of finished produce; and consumers will be concerned with flavour, appearance or cooking qualities of grain.

Grain quality may vary with the variety or type of grain selected by the farmer. It will be influenced by climatic and soil conditions during the growing season, cultivation practices, weather conditions at harvest, and by harvesting techniques. Apart from short-term aging or maturation immediately after harvest, quality cannot be improved during storage, handling and processing - on the contrary, it is easily lost.

Every type of grain can be said to possess properties which contribute to its overall quality. A consideration of the various properties or qualities, either alone or together, allows the

grain to be graded and valued, and enables the design and development of optimum methods for handling, storing and processing.

Research work into methods for the identification of varieties may hold the key to grain grading systems of the future. Consumers are becoming accustomed to buying fruit and vegetables by variety, so why not grain? Most cereal crops have been studied; polyacrylamide gel electrophoresis (PAGE) techniques have been used to discriminate between wheat varieties, and reversed-phase high-performance liquid chromatography (RP-HPLC) techniques may be applicable to wheat and rice.

Assessment of grain quality

With over 420 standard test methods, including at least 75 internationally-applicable, it is apparent that there is a large diversity in grain character. This is obvious when considering the range of uses for grain: paddy to produce milled rice, barley for malting, durum wheat for pasta production etc.

Many assessments are commodity-, product- or end user-specific. Of the wide range of properties, bulk density and foreign matter are commonly assessed for most types of grain. In addition, the influence of moisture content on other grain qualities, as well as the simple economic fact, make it important for quantification.

(i) Bulk Density

All equipment for the determination of bulk density have features of (a) causing the sample material to fall from a standard container through a standard height into a standard volume weighing bucket, (b) levelling the surface of the material in the weighing bucket in such a way as not to influence its packing and (c) weighing the loaded bucket. However, differences in equipment design and procedural detail can result in very different values for bulk density, even when the same grain sample is used. It is essential, therefore, that only one type of apparatus is used for determining bulk density. ISO 7971 is a standard reference method with results expressed as mass per hectolitre.

The bulk density of a sample of grain can also be affected by the presence of foreign matter, and varies with mc. Consequently it is standard practice to remove as much foreign matter as possible by sieving samples before carrying out bulk density determinations, and also to measure the mc of the sieved material.

(ii) Foreign Matter

Most grain quality standards state that the screens in sieves used for the assessment of foreign matter content should consist of perforated metal plate conforming to specifications laid down by national or international standards organisations. Such specifications cover the composition and thickness of the metal plate, the shape and dimensions of the perforations, and the arrangement of the perforations on the plate. Table 3.8 shows some examples of perforation specifications for some grain types.

Table 3.8. Sieve Perforations for Grain.

Grain	Shape	Diameter mm	Breadth x Length mm	Arrangement
Maize	Round (C)	14.0	-	Staggered
"	" (F)	5.0	-	"
Sorghum	" (C)	6.5	-	"
"	" (F)	2.5	-	"
Bulrush millet	" (C)	4.0	-	"
" "	" (F)	1.0	-	"
Wheat	Slot (C)	-	4.5 x 25.0	End Staggered
"	" (F)	-	2.4 x 20.0	"
Paddy	" (C)	-	4.5 x 20.0	"
"	" (F)	-	2.5 x 20.0	"

(C) Coarse Screen, for removing material larger than the grain.
(F) Fine Screen, for removing material smaller than the grain.

Operating Capacity of Sieves

The efficiency of a sieve is dependent upon two factors: the dimensions of the apertures in the screen, and the proportional volume of material which will not pass through the apertures. As a general rule, the percentage sieving area[1] of a screen with small perforations is less than that of a screen with larger holes, and its capacity for sieving efficiently is correspondingly reduced. Also, for a perforated metal screen of fixed specifications the sieving efficiency falls off markedly if the volume of material which will not pass through the apertures exceeds a certain quantity. Table 3.9 shows the recommended volume of grain that should be placed on a screen, to maintain its sieving efficiency.

Table 3.9. Grain Sieves, 200mm Diameter, Maximum Loadings.

Nominal aperture mm	Recommended volume of load cm^3	Typical grain equivalent
8.0	500	300g Maize
4.0	350	250g Sorghum
2.0	200	150g Wheat
1.0	140	100g Millet

Source: International Standard ISO 2591-1973

[1] Total area of holes expressed as a percentage of perforated metal plate unit area.

(iii) Moisture Content

The standard test method (ISO 712) for the determination of mc in cereals is by mass loss in a hot-air oven. The method is time-consuming and a variety of rapid methods have been developed for day-to-day use. These range through accelerated heating by infra-red source gravimetric tests to almost instantaneous readout by electronic moisture meter. Of the latter, two types are common; resistance and capacitance meters.

It is recommended that grain-handling agencies avoid using a mixture of meter types, because this can lead to conflicting results. Instead, the meter best suited to their particular requirements should be selected. The following factors should be considered when selecting a meter to determine moisture content:

Resolution - the ability of the meter to differentiate between moisture contents which are very close in value. Some meters have the ends of the scale compressed i.e. the scale is not linear. The resolution of the meter is therefore relatively poor for high and low readings.

Repeatability - a measure of the meter's ability to give a constant reading when the same sample is tested several times. Capacitance meters, due to variations in grain packing, may not produce such accurate results as resistance meters, which normally use a more homogeneous ground or compressed sample.

Reliability - a measure of variation between meters when measuring the moisture content of the same sample. Meters should be regularly checked and calibrated to ensure reliability.

Stability/drift of measurements - affects the frequency of the need to calibrate the meter against the standard test method.

Range of commodity - calibrations will be necessary for all the commodities of interest, and the meter must be capable of accommodating them.

Range of mc - in general, resistance meters cannot measure low mc, i.e. lower than approximately 9%, whereas capacitance meters can - to 1 or 2% in some cases.

Sample size - meters use differing size of test samples: larger samples give more accurate results, and require fewer replications.

Sample weighing - most capacitance meters require the sample to be weighed, thus introducing an extra variable (and extra cost).

Ambient effect - meter readings vary with temperature, and correction is required. Some meters automatically display the corrected moisture content.

THE ROLE OF STANDARDS IN LOCAL TRADE

Producers of grain will have a number of uses for their produce; as food for the family or livestock, for seed, or for sale. The trade of grains can cover a large area entailing a variety

of end usages. A number of end-users would benefit from the uniformity of supply associated with the use of grain standards, such as the commercial producers of food products e.g. beverages, baked products and animal feed, or the procurers for food security reserves. It is difficult to judge whether the setting of standards for these varied uses can best be carried out by the relevant industry rather than a government regulatory body, or a combination of the two. Whatever method is used to formulate the standards, it gives a clear message of quality requirements to producers, and it should provide a more uniform and regular supply for the end users.

Given that the formulation of standards is the best system for providing information to grain producers and end-users, they should be based on factors which both consider important and which are easily recognisable and unambiguous. The selection of grades must allow clear steps which can be easily differentiated and represent a clear change in value and end-use. Standards should be built on those characters that can be accurately and uniformly measured, and interpreted. To assist this process, terminology must not be difficult to understand.

Above all standards should be sources of information intelligible to all and serving a clear function in the production and utilisation of grain.

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CHAPTER 4

GRAIN HARVESTING, THRESHING AND CLEANING

TECHNICAL ALTERNATIVES

Harvest constitutes a major operation among agricultural activities. Considered for a long time as the last step in production, it must rather be approached as the first one in the post-production system, because of its influence on subsequent processing and preservation of the products.

Harvesting methods differ according to the part of the plant to be used. As regards forage crops, the whole plant is cut, but for underground crops (eg, groundnuts, roots and tubers), the crop is lifted while the soil sticking to it is removed. With cereals, the crop is first cut either as a whole or partially (ears), and then threshed and cleaned to separate the grain from the ears and straw.

In the latter case two main alternatives exist: separate harvesting and threshing, or combined harvesting and threshing.

In developing countries the first alternative is generally the most widely applied. Although harvesting and threshing are still frequently done by hand, their mechanization has begun to develop during recent years, especially where the crop is produced not for self-consumption but rather for commercial purpose. Nevertheless, such mechanization has not developed everywhere to the same extent but according to the type of crop concerned, because labour requirements remain high for handling the produce before threshing.

In industrialized countries, attempts have been made since the beginning of the 20th century to devise machines which would both harvest and thresh grain, so as to reduce the labour requirements involved. Combine harvesters ('combines') which can cut, convey, separate and thresh the grain were the product of this development work. They are in widespread use, and have been used already on large grain production schemes in a number of developing countries.

Rice Harvesting and Threshing

(i) Harvesting methods

<u>Manual harvesting</u>

In many countries rice ears are cut by hand. A special knife is frequently used in South-East Asia ("ani-ani"), Latin America ("cuchillo") and Africa. For instance, in the Casamance region of Senegal rice is cut stem by stem with a knife, 10 cm below the panicle so as to

leave straw in the field in amounts large enough to produce grazing for cattle. Nevertheless such practice is labour intensive.

To harvest denser varieties (500 stems/sq metre instead of 100) a sickle is used mainly on a generally wetter produce. But work times remain high: 100 to 200 man-hours per ha for cutting and stooking.

Mechanized harvesting

During past decades the mechanization of rice harvesting has rapidly evolved. It first developed in Japan, then in Europe and has now reached many tropical countries.

The first machines used were simple animal-drawn (horses in Europe, oxen in the tropics) or tractor-driven mowing machines fitted with a cutter bar. The improvements made on this equipment have first resulted in the development of swathers (Figure 4.1). These drop the crop in a continuous windrow to the side of the machine making it easy to pick up the panicles and manually tie them into bundles. The next step forward has been the reaper that forms unbound sheaves; and finally the reaper/binder which has a tying device to produce sheaves bound with a twine. However the supply, cost and quality of the twine are the main problems associated with the use of such equipment.

The output of these machines varies between 4 and 10 hours per hectare, which is slow. However, they may be usefully introduced into tropical rice growing areas, where hand harvesting results in great labour problems. In temperate countries they have been gradually replaced by combine harvesters.

(ii) Threshing methods

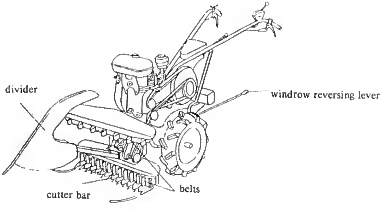
After being harvested paddy bunches may be stacked on the plot. This in-field storage method results in a pre-drying of the rice ears before threshing, the purpose of which is to separate seeds from panicles.

Traditional threshing

The traditional threshing of rice is generally made by hand: bunches of panicles are beaten against a hard element (eg, a wooden bar, bamboo table or stone) or with a flail. The outputs are 10kg to 30kg of grain per man-hour according to the variety of rice and the method applied. Grain losses amount to 1-2%, or up to 4% when threshing is performed excessively late; some unthreshed grains can also be lost around the threshing area.

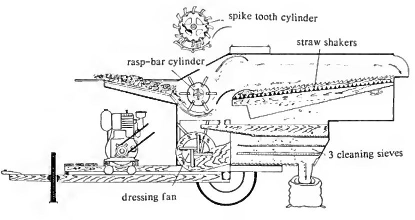
In many countries in Asia and Africa, and in Madagascar, the crop is threshed by being trodden underfoot (by humans or animals); the output is 30kg to 50kg of grain per man-hour. The same method, but using a vehicle (tractor or lorry) is also commonly applied. The vehicle is driven in circles over the paddy bunches as these are thrown on to the threshing area (15m to 20m in diameter around the stack). The output is a few hundred kg per hour. This method results in some losses due to the grain being broken or buried in the earth.

Figure 4.1. Swather.



Source: FAO

Figure 4.2. 'Through-flow' Thresher.



Source: CIRAD

In south-east Asia, total losses induced by traditional harvesting and threshing methods are estimated between 5 and 15%.

Mechanized threshing

From a historical viewpoint, threshing operations were mechanized earlier than harvesting methods, and were studied throughout the 18th century.

Two main types of stationary threshing machines have been developed.

The machines of Western design are known as 'through-flow' threshers because stalks and ears pass through the machine. They consist of a threshing device with pegs, teeth or loops, and (in more complex models) a cleaning-winnowing mechanism based upon shakers, sieves and centrifugal fan (Figure 4.2). The capacities of the models from European manufacturers (eg, Alvan Blanch, Vicon, Borga) or tropical countries (Brazil, India, etc.) range from 500 to 2000kg per hour.

In the 70s, IRRI[1] developed an axial flow thresher which has been widely manufactured at local level. Such is the case in Thailand where several thousands of these units have been put into use. They are generally mounted on lorries and belong to contractors working about 500 hours per year.

More recently, a Dutch company (Votex) has developed a small mobile thresher provided with either one or two threshers (Figure 4.3). The machine has been widely adopted in many rice growing areas. The simple design and work rates of these machines (about 500kg per hour) seem to meet the requirements of rural communities.

The 'hold-on' thresher of Japanese design (Figure 4.4), is so-called because the bundles are held by a chain conveyor which carries them and presents only the panicles to the threshing cylinder, keeping the straw out. According to the condition of the crop, work rates can range between 300kg and 700kg per hour (Iseki model). The main disadvantage of these machines is their fragility.

(iii) Combined harvesting and threshing methods

Combine-harvesters, as the name implies, combine the actions of reaping and threshing. Either the 'through-flow' or the 'hold-on' principle of threshing may be employed, but the reaping action is basically the same. The main difference is that combine-harvesters of the Western ('through-flow') type are equipped with a wide cutting bar (4-5m) while the working width of the Japanese ('hold-on') units is small (1m). According to the type of machine used, and specially to their working width, capacities range from 2 to 15 hours per hectare.

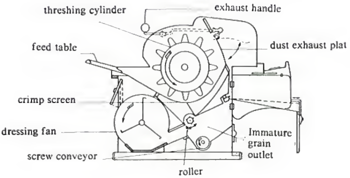
Such machines are being increasingly used in some tropical countries. In the Senegal river delta region, private contractors or farmers' organizations have recently acquired combine

1 International Rice Research Institute (Philippines)

Figure 4.3. "Ricefan" VOTEX thresher in Senegal.

Photo: M. Havard, CIRAD

Figure 4.4. 'Hold on' thresher - Japanese design.



Source: CIRAD

harvesters, mainly of the Western type (Massey Ferguson, Laverda, etc.). So, almost 40% of the Delta surface area is harvested with a pool of about 50 units. Between 200 and 300 hectares of winter rice are mechanically harvested. In this region the popularity of combine harvesters is high despite their poor suitability for some small-sized fields.

In Brazil, several manufacturers have adapted machines to rice growing conditions by substituting tracks for wheels; some machines are simple mobile threshers equipped with cutter bars.

In Thailand, local manufacturers have recently transformed the IRRI thresher into a combine harvester so as to reduce the labour requirement. The unit can harvest 5ha per day and seems to have been rapidly adopted.

(iv) Strippers

Because of their size, conventional harvesters and combine harvesters prove unsuitable for many rice growing areas with small family farm holdings. In response to this problem, research services, during the last ten years, have developed small-sized machines for harvesting the panicles without cutting the straw. Such machines are known as strippers.

In the UK, the Silsoe Research Institute (SRI) has developed a rotor equipped with special teeth for strip-harvesting spikes or panicles. IRRI recently adopted this technology and has developed a 10hp self-propelled 'stripper gatherer' with a capacity of about 0.1ha per hour. However, the harvested grain has to be threshed and cleaned in a separate thresher. Since harvesting unthreshed produce results in frequent stoppages for emptying the machine, this constitutes the main drawback to the progress of the prototype.

In France, CIRAD-SAR has designed and developed a machine which strips panicles from the plants and threshes them in only one pass (Figure 4.5). The stripper has been specially designed for harvesting paddy rice on small plots. The essential component is a wire looped in line with the direction of movement of the machine, which is mounted on a three-wheeled carriage and powered by a 9hp engine. With a 30 cm working width the stripper capacity is about 1 ha per day.

Maize Harvesting and Threshing

(i) Harvesting methods

Manual harvesting

In village farming systems the crop is often harvested by hand, and cobs are stored in traditional structures. Quite often, the crop is left standing in the field long after the cobs have matured, so that the cobs may lose moisture and store more safely after harvest.

During this period the crop can suffer infestation by moulds and insects and be attacked by birds and rodents. To reduce such risks, an old practice (called "el doblado") is sometimes

Figure 4.5. CIRAD/SAR Stripper.

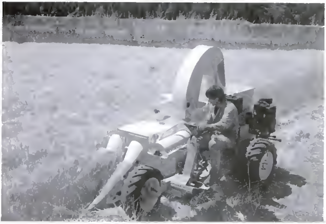
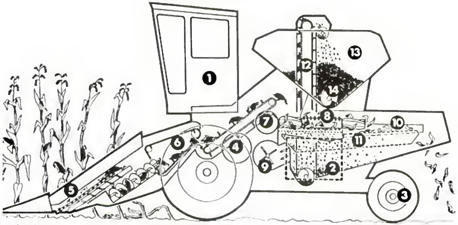


Photo: C. Marouzé, CIRAD

Figure 4.6. Maize sheller.



1 cab
2 engine
3 guide wheels
4 hydraulic speed variator
5 maize header
6 feed conveyor
7 threshing cylinder speed variator
8 threshing cylinder
9 fan
10 cleaning sieve
11 grain auger trough
12 grain elevator
13 hoper
14 unloading auger

Source: CIRAD

applied in South and Central America. This involves hand-bending the ears in the standing crop without removing them from the stalks. It helps mainly to prevent rainwater from entering the cobs, and also limits bird attacks; but, because of the high labour requirements involved, the practice is gradually falling into disuse.

Manual harvesting of maize does not require any specific tool; it simply involves removing the cob from the standing stalk. The work time averages 25 to 30 days per ha. Traditionally, maize cobs are commonly stored in their unhusked form. To improve their drying, it is often recommended to remove the husks from the cobs. Maize husking is usually a manual task carried out by groups of women. Some machine manufacturers (e.g. Bourgoin in France) have developed stationary maize huskers, such as the "Tonga" unit.

Mechanized harvesting

The first mechanized harvester to detach ears of maize from the standing stalks, the 'corn snapper', was built in North America in the middle of the 19th century. This was followed by the development of 'corn pickers', which incorporated a mechanism for removing the husks from the harvested ears. The first animal-drawn maize pickers were replaced by tractor-drawn units (1 or 2 rows) and then tractor-mounted units (1 row). Finally came the development of self-propelled units capable of harvesting from up to 4 rows. A specific feature in maize harvesters is the header which leaves the stalks standing as it removes the ears.

The rates of work can vary from 2 hours per hectare with a 3-row self-propelled harvester to 5 hours per hectare with a tractor-drawn or -mounted single row unit. Generally speaking, harvest losses range from 3% to 5%, but they may be up to 10%-15% under adverse conditions. Depending on the situation, a single-row harvester can be employed effectively on up to 20 hectares or more; but the use of a multi-row machine demands several tens of hectares to be economically effective.

Specially designed for harvesting maize as grain, the corn-sheller was initially a cornhusker in which the husking mechanism was replaced by a threshing one (usually of the axial type). Corn-shellers are self-propelled machines of the 3 to 6-row type with capacities of 1 to 2 hours per hectare (Figure 4.6). The surface areas harvested during a 180-hour campaign range between 100ha (with a 3-row unit) and 200ha (with a 6-row one).

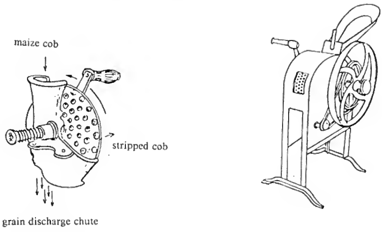
Another alternative consists of equipping a conventional combine with a number of headers corresponding to the machine horsepower. However, although widely used, such a method requires many adjustments to the threshing and cleaning mechanisms.

(ii) Threshing methods

Shelling and threshing

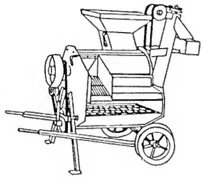
Traditional maize shelling is carried out as a manual operation: maize kernels are separated from the cob by pressing on the grains with the thumbs. According to the operator's ability the work rate is about 10kg per hour. Outputs up to 20kg per hour can be achieved with hand-held tools (wooden or slotted metal cylinders). To increase output, small disk shellers

Figure 4.7. Maize hand shellers.



Source: CIRAD

Figure 4.8. "Bamba" motorized maize sheller.



Source: M. Havard, CIRAD

such as those marketed by many manufacturers can be recommended (Figure 4.7.). These are hand-driven or powered machines which commonly require 2 operators to obtain 150kg to 300kg per hour. Another threshing method, sometimes applied in tropical countries, involves putting cobs in bags and beating them with sticks; outputs achieved prove attractive but bags deteriorate rapidly.

Motorized threshing

Nowadays many small maize shellers, equipped with a rotating cylinder of the peg or bar type, are available on the market. Their output ranges between 500 and 2000kg per hour, and they may be driven from a tractor power take off or have their own engine; power requirements vary between 5 and 15hp according to the equipment involved. For instance the French Bourgoin "Bamba" model (Figure 4.8) seems well-suited to rural areas in developing countries because of its simple design, easy handling and versatility (maize, millet sorghum, etc.).

Millet and Sorghum Harvesting and Threshing

(i) Manual harvesting

In Africa, and especially in the Sudano-Sahelian area, these cereals constitute the staple food in the human diet. They are harvested almost exclusively by hand, with a knife (Figure 4.9) after unrooting or bending the taller stems to reach the spikes. Harvesting and removal from the field takes 10 to 20 days per hectare, according to yields. Harvested ears are stored in traditional granaries while the straw is used as feed for cattle or for other purposes (e.g. thatching).

(ii) Gradual mechanization of threshing

Women separate the grain from the ears with a mortar and pestle, as it is needed for consumption or for marketing purpose (Figure 4.10). The threshed grain is cleaned by tossing it in the air using gourds or shallow baskets.

This traditional method is arduous and slow (10kg per woman-day). Consequently, research has been conducted for some years on how to mechanize it.

The mechanical threshing of sorghum ears does not raise any special problems: conventional grain threshers can be used with some modifications; such as adjustment of the cylinder speed, size of the slots in the cleaning screens, etc. On the other hand, the dense arrangement of spikelets on the rachis and the shape of millet ears (especially pearl millet), make their mechanical threshing excessively difficult.

The first millet and sorghum threshers were developed in Senegal in the 1960-70s: the Siscoma BS 1000 and the Marot DAK 11. Giving relatively high outputs (about 1000kg per hour) they have been intended for village farmers'groups, cooperatives or private contractors going from village to village to work on big threshing layouts. The multipurpose "Bamba" thresher, better suited to rural communities, has a capacity of about 300kg per hour. The

Figure 4.9. Knife ("ngobane") for harvesting millet.

M. Havard, CIRAD

Figure 4.10. Traditional threshing of millet with a mortar.

Photo: M. Havard, CIRAD

Senegalese pool of millet and sorghum threshers currently amounts to 120-150 units.

As regards mechanized harvesting at family level, some hand-operated threshers (Champenois) were developed and tested experimentally but they did not prove very successful. CIRAD is currently working on the design of powered millet threshers of low capacities (50 to 100kg per hour).

Grain Cleaning

Threshing operations leave all kinds of trash mixed with the grain; they comprise both vegetable (e.g. foreign seeds or kernels, chaff, stalk, empty grains, etc.) and mineral materials (e.g. earth, stones, sand, metal particles, etc.), and can adversely affect subsequent storage and processing conditions. The cleaning operation aims at removing as much trash as possible from the threshed grain.

The simplest traditional cleaning method is winnowing, which uses the wind to remove light elements from the grain (Figure 4.11).

(i) Mechanized cleaning

The most rustic equipment is the winnower (Figure 4.12): a fan-originated current of air passes through several superposed reciprocating sieves or screens. This type of machine was widely used in the past for on-farm cleaning of seed in Europe. It can be either manually powered or motorised; capacities range from a few hundred kilogrammes to several tonnes per hour.

In Europe, with the use of combine harvesters and the development of centralized gathering, cereal winnowers have been progressively replaced by seed cleaners in the big storage centres. These machines, also equipped with a system of vibrating sieves, are generally capable of very high outputs (several tens of tonnes per hour).

In developing countries, mechanizing the cleaning operation at village level has seldom been felt as a necessity, because of the lack of quality standards in grain trading. However, because of the current trend towards privatization of marketing networks, the demand for cleaning machines will probably increase. The local manufacture and popularization of simple and easily portable equipment, such as winnowers or screen graders suited to cereal crops, need to be encouraged. CIRAD/SAR has recently developed cleaning machines of the rotary type with outputs of a few hundred kilogrammes per hour.

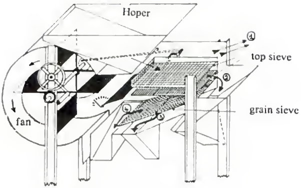
CONSTRAINTS

Because there is a wide choice of equipment available for both harvesting and threshing, it is not easy to select the machinery most appropriate to a particular situation. It is very important, therefore, to identify the constraints specific to each situation before selecting equipment.

Figure 4.11. Traditional wind cleaning of paddy.

Photo: M. Havard, CIRAD

Figure 4.12. Cereals winnower.



1 light matérial (air exhaust)
2 foreign trashes
3 second quality grain
4 first quality grain

Source: DARRAGON

Technical Constraints

(i) Cropping and Farming Systems

Previous analyses of the cropping and farming systems are required to determine the actual needs regarding mechanization: location of the land under cultivation, intensification level, prices of products, etc.

The mechanization of the harvesting operation for crops - mainly food crops - with yields ranging between 0.5 and 2 tonnes per ha rarely justifies itself economically.

On the other hand, mechanizing the harvesting operation will be more easily justified on an intensified irrigated area of several hectares with paddy rice as main crop, where small farmers can group together, and the sale price for paddy is sufficiently attractive.

(ii) Cropping Conditions

The constraints affecting harvesting and threshing operations which influence the quality of the product are: the moisture content of the grain at harvest time, the maturity of the crop, the type of plant involved and the way it stands in the field.

The moisture content of the grain must be between 18 and 23% at harvest time, or between 12 and 20% at the threshing stage. These guidelines determine the start of operations. Below such values, losses (in the case of rice) from shattering during harvest and breakage during threshing are excessively high and bad for the subsequent processing. Above such values, problems arise at storage level: risks of moulds developing and germination of the grain in stooks, drying cribs or granaries.

Crop maturity and type directly affect mechanization and *vice versa*. The introduction of mechanized technology has reduced the tendency to plant mixed varieties of grain: single variety crops ripen uniformly thus making it easier to harvest or thresh them mechanically. With crops which do not mature at one time, the choice of the date for performing the harvesting operation will determine the results: for paddy an earlier harvest will generally result in low yields and high percentage of unripe grain; on the other hand, delayed harvesting will lead to shattering losses, higher percentage of broken grain at the processing level, etc. In addition, the weed infestation level will affect the use of machines and also the cleanliness of the harvested and threshed materials.

The type of plant influences both the choice of machines and their performance:

- the grain-straw ratio must be as high as possible to limit the volume of straw entering the machine;

- the attachment of the grains to the panicles or spikes must allow relatively easy stripping at maturity;

- erect and short stemmed varieties are preferred (paddy varieties with very curved grain ears make it necessary to cut high proportions of

straw, and tall varieties of maize, millet and sorghum prove difficult to mechanize);

- the abrasive property of certain seeds (eg, paddy) makes it necessary to use high quality materials in the manufacture of machines.

To meet these objectives, it is necessary to observe a very strict work schedule, especially for wetland paddy. Accordingly, machines must be able to work under particularly difficult conditions: in the mud with special attachments (tracks, cage-wheels, etc.) before the complete drainage of rice fields, at low working speeds, on a produce difficult to cut because still partially green, and handling of a product often soiled with mud.

Social and Labour Constraints

Harvesting is a labour-intensive operation but is less arduous than threshing. Because most of the rural population consider threshing as a particularly tedious operation (especially in the case of millet), grain producers accept the relatively high cost of mechanical threshing.

The skills and experience of farmers, and the interests of traditional systems, must necessarily be taken into account when mechanizing certain operations. It will be easier to extend the use of harvesting machines where farmers are already employing other powered equipment such as tractors, motor pumps or processing units. The availability of workers skilled in the operation, maintenance and repair of engine-powered equipment favours the adoption of new machines.

Lastly, in developing countries harvesting and threshing operations are traditionally carried out by women. However, in most situations, as these operations become mechanized, they are taken over by men and the role of women is reduced to winnowing and the gleaning of grain scattered during harvesting and threshing. The mechanization of post-harvest operations frequently means the transfer of activities from women to men.

Economic Constraints

Economic constraints are a drawback to the purchase of farm machinery. The high costs involved, above individual farmers'resources, allow the acquisition of such equipment only if credit and the possibility of farmers grouping together exist. Alternatively, if private individuals are interested in equipping themselves, they can hire out their services to the rest of the community.

To justify and encourage the purchase of machines, technical versatility can be an incentive (e.g. a rice thresher which can also be used for threshing millet and maize), even if the equipment proves less efficient with certain crops than a specific single-purpose one. In such a case, the choice of the equipment should be made according to the crop which is mechanized first.

In practice, the costs of machines and services vary from one country to another. By way of example, the following 1992 tax-free prices for some machines in Senegal are given for comparison:

- Thresher, Votex Ricefan	1,100,000 Fcfa
- Thresher, SISMAR[2], Borga type	7,700,000 Fcfa
- 120hp rice combine harvester	24,000,000 Fcfa
- Millet thresher, SISMAR (without tractor)	7,700,000 Fcfa
- Multipurpose Bamba thresher, Bourgoin	2,200,000 Fcfa

Supplied services are generally paid a percentage of the crop: 5 to 10% for threshing and 15 to 20% for combine harvesting.

In Mali, the cost of using the Votex thresher is estimated to be between 3 and 5% of the grain produced (paddy at about 70 Fcfa per kg); assuming that the useful life is 10 years for the thresher (7 years for the engine), and that the working parts will need replacing after processing every (a) 80t for the thresher teeth, (b) 800t for the crimp screen and (c) 1000t for the thresher unit (toothed shaft and fan).

These figures must be considered as basic, because the profit margins of manufacturers and retailers of spare parts are not taken into account, and also because prices can be higher in other countries (as in Senegal).

Organization of the Distribution System

The introduction and extension of new machines is easier if distribution systems for machines and spare parts, and local industrial or artisan manufacturing facilities exist already.

Compared with animal-drawn implements, powered harvesting and threshing machines are difficult to manufacture. Research has been conducted into the design of simplified equipment which can be manufactured locally, e.g. the IRRI and Votex threshers.

Support from technological transfer projects has often been needed for the local production of some machines: the Votex Ricefan thresher in Mali and Senegal, for example. This thresher has been designed to cope with transport problems and allow local assembly or even partial manufacture.

Local construction will develop in several steps:

1. The assembly of imported kits;
2. Partial manufacture, except cylinder and gear case, by using cutting, punching, drilling and welding jigs; and
3. Total manufacture, except some elements made of high-quality steel.

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2 Société Industrielle Sahélienne de Mécaniques, de Matériels Agricoles et de Représentation.

Theoretically, local manufacturing offers various advantages such as reduced profit margins to retailers and transport costs (100 kits in one container instead of 22 Votex threshers, etc.), but also some drawbacks (quality of construction and employed materials, adverse taxation and customs regulations, etc.).

Training Needs

In most developing countries, mechanization is far removed from traditional practises and its acceptance is a delicate matter for many farmers. Accordingly, training is a key element in the successful adoption of engine-powered machines by farmers.

Appropriate training of several types is required:

- farmers need to be informed about how credit schemes to purchase equipment function;

- then they need to be made aware of the conditions suitable for harvesting and threshing which will reduce the costs of these operations and improve the quality of the product obtained;

- farmers require training on the management of equipment: while operators and mechanics need to learn about the maintenance and running of equipment;

- management staff will need training in work organization, projecting running costs, and maintaining operational accounts;

This training should be complemented by supplying information on, and demonstrating, new harvesting, threshing and cleaning equipment to farmers so as to increase their awareness of the range of machines available.

EVALUATION OF COSTS

Size of Investments

Agricultural practices in industrialized countries have become complex and almost completely mechanized. In contrast, in developing countries, only some operations are mechanized while others continue to be manual or use animal-drawn implements.

The scale of mechanisation depends on the type of farm and working methods. Thus, the size of investment varies greatly from one situation to another: assuming a given value of 1 for a pedal-operated thresher, it is between 10 and 60 for a power-driven unit and between 60 and 300 for a combine harvester.

Accordingly, if a pedal-operated thresher can be purchased by a farmer with a 2 to 3 hectare farm, a powered unit or a combine harvester can be purchased only by groups of farmers or private contractors provided that financial means (agricultural credit, technical aid, etc.) are made available. Lastly, the choice of equipment must be justified economically, cost-effective, and capable of increasing work productivity.

The same consideration applies to the different harvesting and cleaning machines. In addition, prior to any investment the total operating cost of the equipment must be estimated.

Calculation of Operating Costs

Theoretically, the costs of mechanized operations are easily calculated when all the expenses involved are known. This is not always the case in developing countries.

(i) Estimated operating cost

The cost of using farm machinery is generally calculated as a cost per hour. This provides useful information for deciding whether to purchase equipment, the type of machine to be selected and the renting rates to be applied in case of collective use of the equipment.

Such estimates are necessary for loan companies, dealers selling on a credit basis or agencies funding large-scale investment operations.

Fixed costs

These are independent of how much the equipment is used per year. They include the interest on capital (generally at the rate applied by local companies on medium-term loans to farmers), possible taxes, levies and shelter charges, and also insurance premiums if any.

In developing countries, only interest on the capital invested (return on tied-up capital) is considered. Insurance is taken into account only for the purchase of large equipment on a credit basis (a requirement of the loan company). There are very few farmers or farmers'groups who invest in buildings to shelter their equipment.

Rates usually applied are as follows:

- capital interest (half of the average rate applied by the loan company),
- insurances: fire, third-party claim (0.5 to 1% of the purchase price),
- shelter (0.5 to 1% of the purchase price),
- sales tax, duty, vehicle licence, etc.

Costs variable under certain conditions

These include depreciation, and repair charges for the equipment.

The cost of depreciation is the original cost distributed over the estimated useful life of the equipment in order to recover the capital required for its replacement.

When the expected annual hours of use are higher than the ratio of depreciation period in hours to the number of years of use, depreciation must be charged to variable costs. Below this value, it is charged to fixed costs.

In developing countries, depreciation as regards the purchase price (resale value supposed nil) also includes transport, handling, installation and starting up costs.

The depreciation period is expressed as a quantity of work (hours or hectares) and as a number of years. For a loan company such value must never be below the life of the loan granted.

Repair charges include the costs of labour and spare parts. They are generally related to the purchase value using coefficients calculated from surveys among manufacturers and repairers in industrialized countries. The same coefficients are used in developing countries , because relevant information concerning them is rather scarce: the costs of spare parts may be higher, but this is compensated for by the lower cost of labour.

Table 4.1. Estimated useful life and repair coefficients for some agricultural machines.

Equipment	Depreciation		Repair
	Years	Hours	coefficients
Wheeled tractor	6	6000	0.5
Harvester	5	2000	0.5
Thresher	10	5000	0.7
Combine harvester	6	3500	1

Note: These figures are only indicative and are subject to high variation depending upon how the equipment is used.

Actually variable costs

These costs are proportional to the annual working time; they include the costs of fuel, lubricants, operation and maintenance.

Fuel consumption is expressed as: 0.19l/hp/hour for petrol engines and 0.12l/hp/hour for diesel engines.

Coefficients must be adjusted according to the nature of the work undertaken by the equipment when in operation. For example, in Senegal an average consumption of 10l/h, travel time included, has been recorded for 123hp combine harvesters (i.e. 0.08l/hp/hr) and

10l/hr for 100hp tractors (i.e. 0.10l/hp/hr) with offset attachments for tillage. Such values must be used with care because they vary according to the work performed (engine power required) and the method of recording work time - see (ii) below. For more accuracy they can be easily verified in the field for different types of work.

Lubricant consumption is calculated from the engine consumption. For tractors and combine harvesters, oil changes for the gearbox, axle and hydraulic system must be taken into account. Average values can be given as follows:

- 2.5l/100l of fuel for engines,
- 4.5l/100l of fuel for tractors and combines

Labour costs (operator, mechanic, 'equipment manager', etc.) and supplementary expenses are estimated according to local wages (on an hourly, monthly or piece-work basis) to which must be added travel costs and sundry expenses (transport, maintenance supplies, close support vehicle, etc.).

In many developing countries labour costs and sundry expenses may be high: e.g. in the Senegal river valley 5 workers (1 operator, 1 apprentice, 1 'pointeur'[3], 1 mechanic and 1 manager) plus one permanent support car are required for a combine harvester.

(ii) Observation on some elements of calculation

Depreciation is the key factor which determines whether mechanization projects can be repeated or sustained. Many such projects have disappeared because they were unable to incorporate sufficient reserves for amortizement.

Efforts to evade such problems include:

- systematically borrowing the capital required for replacing the equipment and repaying the loan plus interest; that is coping with amortization without taking account of technical depreciation;

- settling the loan and partially allowing for technical depreciation; thus making part down-payment possible when the equipment is replaced.

Estimating the annual working time is of upmost importance. For a tractor one generally allows 1000 working hours. The basic factors used for calculating the expected working time are (a) the time required for each operation with the equipment concerned, and (b) the area worked.

The stock of spare parts must be carefully examined because it corresponds to locked-up funds. It is composed according to the distance from suppliers, the size and features of the equipment pool, and the working conditions of the machines. Suppliers' lists must be adapted to local requirements.

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[3] one who counts the paddy bags and takes receipts in kind.

The operating cost per hour of farm machinery permits the cost of the corresponding cultural operation to be determined. This will vary according to the time required for the operation, equipment used, working conditions, skill of the work force, and the distance of the working site.

The efficiency of the equipment is the time required for carrying out the work with it. The 'theoretical' efficiency is the capacity per hour derived from the technical specifications of the machine concerned; the 'actual' efficiency is expressed as working time in the field; and the 'practical' efficiency is the working time which also includes time for stoppages, turning, making adjustments, etc.

In the Senegal delta region, for example, the theoretical efficiency of a combine harvester is 1 hour per hectare (4t/hr for a 4t/ha crop); with a travelling speed of 2.2km per hour for an actual working width of 3.9m (cutter bar 4.2m wide), its actual output is 1 hour and 30 minutes per hectare, while its practical output is 2 hours and 30 minutes per hectare when time for travel, hopper emptying, etc., are included.

(iii) Actual operating cost

The actual operating cost can be determined after an operation, a campaign or at the conclusion of the pay out period. Some aspects must not be omitted, such as repair costs increasing as the equipment gets older, and the market value of actual expenses when the currency used is not stable.

The actual operating cost determined at the start of actual expenditure assumes value only in terms of the references in which it was established. The method of calculation is the same as that used for estimating costs (see above), but employs data actually recorded during the reference period. Such data must be written down in the log-book and 'monitoring book'.

The log-book is kept with the equipment everywhere it goes; it is used to record the following data:

- operations performed, i.e. type and features (surface area, weight, distance, etc.), work duration;

- lubricant and fuel consumptions;

- repairs and maintenance (time and products required).

The monitoring book is kept at the farm and records the history of the machine; it must comprise:

- general data such as the purchase date and price, commissioning costs, value of the stock of spare parts, supplier address, etc.,
- the work performed per campaign (or per year) and working hours;
- the expenses and receipts per campaign (or per year) ie, repairs, fuels, lubricants, labour, sundries, receipts from custom services, etc.

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CHAPTER 5

DRYING METHODS

INTRODUCTION

There is an essential need to dry grain quickly and effectively after harvest and before storage to retain maximum quality, to attain a moisture content sufficiently low to minimise infestation by insects and microorganisms (bacteria, fungi, etc.), and to prevent germination.

Wherever possible, it is traditional to harvest most grain crops during a dry period or season and simple drying methods such as sun drying are adequate. However, maturity of the crop does not always coincide with a suitably dry period. Furthermore, the introduction of high-yielding varieties, irrigation, and improved farming practices has led to the need for alternative drying practices to cope with the increased production, and grain harvested during the wet season as a result of multi-cropping.

Natural methods of drying make use of exposure of the wet grain to the sun and wind. Artificial dryers employ the application of heat from combustion of fossil fuels and biomass resources, directly or indirectly, and in both natural and forced convection systems. Mechanical dryers, long used in developed countries, are finding increased application as farming and grain handling systems develop.

DRYING PRINCIPLES AND GENERAL CONSIDERATIONS

Drying Mechanisms

In the process of drying heat is necessary to evaporate moisture from the grain and a flow of air is needed to carry away the evaporated moisture. There are two basic mechanisms involved in the drying process; the migration of moisture from the interior of an individual grain to the surface, and the evaporation of moisture from the surface to the surrounding air. The rate of drying is determined by the moisture content and the temperature of the grain and the temperature, the (relative) humidity and the velocity of the air in contact with the grain.

Figure 5.1 demonstrates the drying of a single layer of grain exposed to a constant flow of air. The moisture content falls rapidly at first but as the grain loses moisture the rate of drying slows. In general the drying rate decreases with moisture content, increases with increase in air temperature or decreases with increase in air humidity. At very low air flows increasing the velocity causes faster drying but at greater velocities the effect is minimal indicating that moisture diffusion within the grain is the controlling mechanism.

Grains are hygroscopic and will lose or gain moisture until equilibrium is reached with the surrounding air. The **equilibrium moisture content** (EMC) is dependent on the relative humidity and the temperature of the air; EMCs for a range of grains are shown in Table 5.1.

The relationship between EMC, relative humidity and temperature for many grains has been modelled by numerous researchers; the results of which have been summarized by Brooker *et al.* (1974).

Table 5.1. Grain Equilibrium Moisture Contents.

Grain	Relative Humidity (%)							
	30	40	50	60	70	80	90	100
	Equilibrium Moisture Content (%wb*) at 25°C							
Barley	8.5	9.7	10.8	12.1	13.5	15.8	19.5	26.8
Shelled Maize	8.3	9.8	11.2	12.9	14.0	15.6	19.6	23.8
Paddy	7.9	9.4	10.8	12.2	13.4	14.8	16.7	-
Milled Rice	9.0	10.3	11.5	12.6	12.8	15.4	18.1	23.6
Sorghum	8.6	9.8	11.0	12.0	13.8	15.8	18.8	21.9
Wheat	8.6	9.7	10.9	11.9	13.6	15.7	19.7	25.6

* wet basis Source: Brooker *et al.* (1974)

It is very important to appreciate the practical significance of the EMC. Under no circumstances is it possible to dry to a moisture content lower than the EMC associated with the temperature and humidity of the drying air; for example, the data in Table 5.1 show that paddy can only dry to a moisture content of 16.7% when exposed to air at 25°C and 90% relative humidity. If paddy at a moisture content less than 16.7% is required then either the temperature of the drying air has to be increased or its humidity reduced.

The drying of grains in thin layers where each and every kernel is fully exposed to the drying air can be represented in the form:

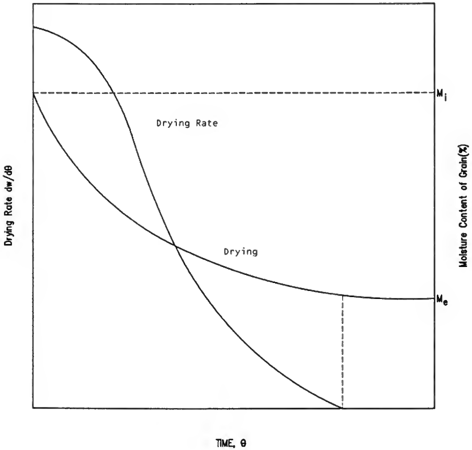
$$\mathbf{MR} = f(\mathbf{T}, \mathbf{h}, \mathbf{t}); \qquad (1)$$

where $\mathbf{MR} = \dfrac{\mathbf{MC} - \mathbf{MC_e}}{\mathbf{MC_o} - \mathbf{MC_e}}$ (the moisture ratio);

MC is the moisture content of the grain at any level and at any time, % dry basis (%db);
$\mathbf{MC_e}$ is the equilibrium moisture content (%db);
$\mathbf{MC_o}$ is the initial moisture content of the wet grain (%db);
T is the air temperature (°C);
h is the air relative humidity; and
t is the drying time.

Empirical data have been used to determine mathematical approximations of the relationship between drying rate and air conditions. Relationships for many grains have been summarized by Brook & Foster (1981). For example, a thin layer equation for paddy (Teter 1987) is:

Figure 5.1. Drying and Drying Rate Curves.



M_i = Initial Moisture content, and M_e = Equilibrium Moisture content

$$\mathbf{MR} = \exp.(-\mathbf{X} * t^{\mathbf{Y}}): \qquad (2)$$

where $\mathbf{X} = 0.026 - 0.0045h + 0.01215T$; and
$\mathbf{Y} = 0.013362 + 0.194h - 0.000177h^2 + 0.009468T$,
with **h** expressed as a percentage, and T in °C.

In the drying of grain in a deep bed, whilst individual kernels may all be losing moisture at different rates, the overall drying rate will remain constant for a long period. The air absorbs moisture as it moves through the bed until it becomes effectively saturated and moves through the remaining layers of grain without effecting further drying. Figure 5.2A shows the three zones present within a thick drying bed at an intermediate time within the drying operation. Drying takes place within a discrete zone, the size of which depends on the moisture content of the grain and the temperature, humidity and velocity of the air. Below the drying zone is the dried zone where the grain is in equilibrium with the air. Above the drying zone is the un-dried zone wherein the grain remains unchanged from its initial condition. In a shallow bed as in Figure 5.2B the drying zone is thicker than the bed depth and drying would occur initially throughout the bed.

The change in temperature and humidity of air as it moves through a bed of grain depends on the rate at which moisture is being evaporated from each kernel as an individually exposed element. Knowledge of the effect of grain moisture content, other grain properties, the temperature, humidity and flow rate of the air upon fully exposed kernels is essential to an understanding of how drying would proceed within a bed.

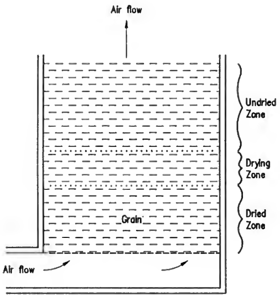
Unfortunately no theory has been developed that accurately and practically describes the thin layer drying rate. As described above many empirical relationships have been established and these have to be used in prediction of drying time (see below). Accurate prediction of drying time is further inhibited by the variability of key factors encountered in practice, particularly so for the simple drying systems that are the most appropriate for use in developing countries. For example the moisture content of individual grains is likely to vary considerably within a batch and in the case of drying with a heater of constant heat output the temperature of the drying air will vary with changes in ambient air temperature.

Air Properties

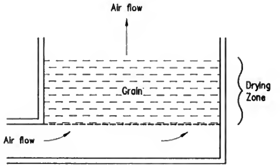
The properties of the air flowing around the drying grain are a major factor in determining the rate of removal of moisture. The capacity of air to remove moisture is principally dependent upon its initial temperature and humidity; the greater the temperature and lower the humidity the greater the moisture removal capacity of the air.

The relationship between temperature, humidity and other thermodynamic properties is represented by a psychrometric chart as shown in Figure 5.3. It is important to appreciate the difference between the absolute humidity and relative humidity of air. The absolute humidity is the moisture content of the air (mass of water per unit mass of air) whereas the relative humidity is the ratio, expressed as a percentage, of the moisture content of the air at a specified temperature to the moisture content of air if it were saturated at that temperature.

Figure 5.2. Drying Zone in Fixed-bed Drying.



A. Thick drying bed.



B. Shallow drying bed.

Figure 5.3. CIBS Psychrometric Chart.

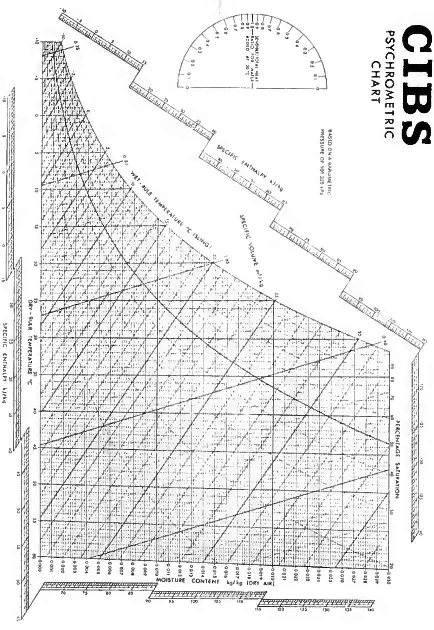
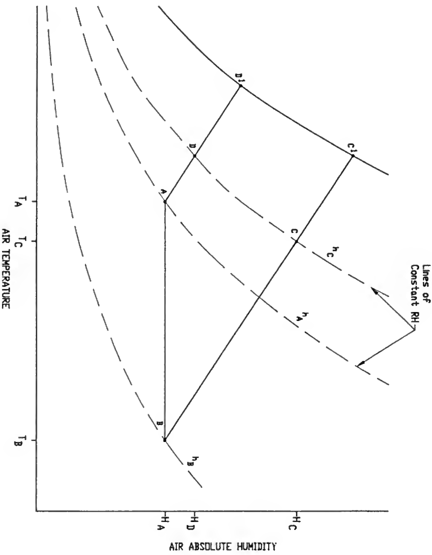


Figure 5.4. Representation of Drying process.



The changes in air conditions when air is heated and then passed through a bed of moist grain are shown in Figure 5.4. The heating of air from temperature $\mathbf{T_A}$ to $\mathbf{T_B}$ is represented by the line **AB**. During heating the absolute humidity remains constant at $\mathbf{H_A}$ whereas the relative humidity falls from $\mathbf{h_A}$ to $\mathbf{h_B}$. As air moves through the grain bed it absorbs moisture. Under (hypothetical) adiabatic drying sensible heat in the air is converted to latent head and the change in air conditions is represented along a line of constant enthalpy[1], **BC.** The air will have increased in both absolute humidity, $\mathbf{H_C}$, and relative humidity, $\mathbf{h_C}$, but fallen in temperature, $\mathbf{T_C}$. The absorption of moisture by the air would be the difference between the absolute humidities at C and B, $(\mathbf{H_C}\text{-}\mathbf{H_A})$.

If unheated air was passed through the bed the drying process would be represented along the line **AD**. Assuming that the air at D was at the same relative humidity, $\mathbf{h_C}$, as the heated air at C then the absorbed moisture would be $(\mathbf{H_D}\text{-}\mathbf{H_A})$, considerably less than that absorbed by the heated air $(\mathbf{H_C}\text{-}\mathbf{H_A})$.

Physical Properties of Grain

Comprehensive data on the numerous physical and thermal properties of grain are available in texts such as Brooker *et al.* (1974) and Brook & Foster (1981).

Moisture Content.

Convention dictates that moisture contents of grains are usually measured on a wet basis, ie the mass of moisture per unit mass of wet grain and written as **X**%(wb). The alternative measure refers to the measurement on a dry basis (**X**%(db)) which is the mass of moisture per unit mass of completely dry grain. Conversion between the two measurements is shown in Table 5.2. All moisture contents given in the text are on a wet weight basis, unless otherwise stated. Table 5.3 shows the mass of water lost from wet grain during drying for a range of initial and final moisture contents.

Table 5.2. Conversion of Moisture Contents.

Wet Basis %	Dry Basis %
10.0	11.0
11.0	12.3
12.0	13.6
13.0	15.0
14.0	16.3
15.0	17.6
16.0	19.0
17.0	20.5
18.0	21.9
19.0	23.5
20.0	25.0
21.0	26.5
22.0	28.2
23.0	29.9
24.0	31.6
25.0	33.3
26.0	35.1
27.0	37.0
28.0	38.9
29.0	40.8
30.0	42.8

Bulk Density.

The bulk density of grain is the weight per unit volume. Moisture content has an appreciable effect on the bulk density (see Chapter 3 for more detail).

[1] Enthalpy = Heat contained in the air

Resistance to Air Flow.

The energy required to force air through a bed of grain is dependent on the air flow, the grain depth and physical properties of the grain such as surface and shape factors, the kernel size distribution, moisture content, and the quantity and nature of contamination, stones, straw, weeds etc. The relation between air flow and the pressure drop generated across the bed for selected grains is illustrated in Figure 5.5. The data generally refer to clean and dry grain and correction factors of up to 1.4 are used for very wet and dirty grain (Teter 1987).

Table 5.3. Moisture loss during drying.

Initial Moisture Content %(wb)	Final Moisture Content %(wb)								
	19	18	17	16	15	14	13	12	11
	Moisture Loss (kg/tonne)								
30	136	146	157	167	176	186	195	205	213
29	125	134	145	155	165	174	184	193	202
28	111	122	133	143	153	163	172	182	191
27	99	110	120	131	141	151	161	170	180
26	86	98	108	119	129	140	149	159	169
25	74	85	96	107	118	128	138	148	157
24	62	73	84	95	106	116	126	136	146
23	49	61	72	83	94	105	115	125	135
22	37	49	60	71	82	93	103	114	124
21	25	37	48	60	71	81	92	102	112
20	12	24	36	48	59	70	80	91	101
19		12	24	36	47	58	69	80	90
18			12	24	35	47	57	68	79
17				12	24	35	46	57	67
16					12	23	35	45	56
15						12	23	34	45

Latent Heat of Vaporization. Energy in the form of heat must be supplied to evaporate moisture from the grain. The latent heat of vaporization, **Lh**, for a grain depends on its moisture content and temperature and is appreciably greater than the latent heat of evaporation of water. The latent heat of vaporization for paddy at selected moisture contents and temperatures is shown in Table 5.4. Data for other grains have been reported by Brooker *et al.* (1974)

Estimation of Drying Time

A basic design procedure for the field worker is best illustrated for the design of a batch type dryer although the principles can be applied to a certain extent in the design of continuous multi-stage systems.

Assumed ambient air conditions are a dry bulb temperature of T_a and a relative humidity of RH_a; from the psychrometric chart the wet bulb temperature, T_{wa}, the enthalpy, H_a, and the absolute humidity h_a can be derived. The air is heated to a selected safe drying temperature, T_h, thereby raising the enthalpy of the air to H_h.

Table 5.4. Latent Heat of Vaporization of Paddy.

Temperature	Latent Heat of Vaporization (kJ/kg)					
°C	Free	Moisture Content %(wb)				
	Water	14	16	18	20	22
25	2,443	2,605	2,518	2,483	2,464	2,453
30	2,431	2,593	2,506	2,471	2,452	2,441
35	2,419	2,580	2,493	2,458	2,440	2,429
40	2,407	2,567	2,482	2,447	2,428	2,417
45	2,395	2,555	2,469	2,434	2,416	2,405
50	2,383	2,542	2,456	2,422	2,404	2,393
55	2,371	2,529	2,444	2,410	2,391	2,381
60	2,359	2,516	2,432	2,398	2,379	2,369

The wet grain of equivalent bone-dry mass **G** has a moisture content of **MC_w**%(db) and is to be dried to a moisture content of **MC_d%**. A mass air flow of **V** is available.

The moisture, **M**, to be removed,

$$M = G * (MC_w - MC_d). \qquad (3)$$

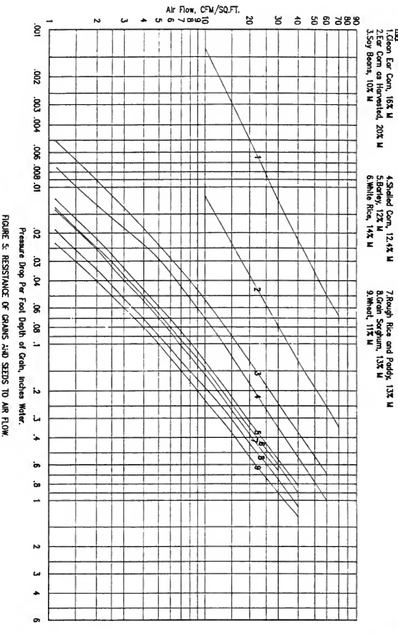
It is assumed that throughout the drying period the air will exhaust from the bed at a constant wet bulb temperature and in equilibrium with the uppermost layers of grain. Initially the exhaust air will be in equilibrium with grain at MC_w moisture and finally in equilibrium with grain at **MC_d** moisture. By superimposing equilibrium moisture content data on to the psychrometric chart for the initial and final moisture contents the humidity of the exhaust air at the beginning and end of drying can be found. An average of the initial and final exhaust air relative humidities, **h_{ea}** is taken for calculation of drying time, **t_d**:

$$t_d = \frac{M}{V * (h_a - h_{ea})} . \qquad (4)$$

An alternative, more complex but more accurate method for the estimation of drying performance is the technique based on dimensionless drying curves as initially developed by Hukill (1947). The methodology permits the estimation of the moisture content of grain at any level within the bed at any time after initiation of drying. It can be used for any grain for which EMC and thin layer drying data are available as is the case for most cereal grains.

The methodology involves the use of bulk drying curves as depicted in Figure 5.6 and calculation of three parameters, **moisture ratio**, **time unit** and **depth factor**.

Figure 5.5. Resistance of Grains and Seeds to Air Flow.



The moisture ratio, **MR** is calculated from Equation 1:

$$\mathbf{MR} = \frac{\mathbf{MC - MC_e}}{\mathbf{MC_o - MC_e}}$$

The time unit, **Y**, is calculated using the equation:

$$\mathbf{Y} = \frac{\mathbf{t_d}}{\mathbf{t_{0.5}}}, \tag{5}$$

where $\mathbf{t_{0.5}}$ is the half-response time, the time required for fully exposed grain to reach a moisture ratio of 0.5 under the drying air conditions employed. It can be calculated from the thin layer drying equations as in Equation 1 with MR assigned a valuc of 0.5.

The depth factor, **D**, is defined as the depth of the bed that contains the mass of grain, **DM**, that can be dried from the initial moisture ratio **MR** = 1 to a final moisture ratio **MR** = 0 with the sensible heat available over the period of one half-response time as the air cools to its wet bulb temperature. **DM** is calculated thus:

$$\mathbf{DM} = \frac{\mathbf{V * C_p * t_{0.5} * (T_{db} - T_{wb})}}{\mathbf{L_h * (MC_o - MC_e)}}, \tag{6}$$

where $\mathbf{C_p}$ is the specific heat of air.

The number of depth factors within the bed is found from the expression:

$$\mathbf{D = d} * \frac{\mathbf{G}}{\mathbf{DM}}, \tag{7}$$

where **d** is the bed depth.

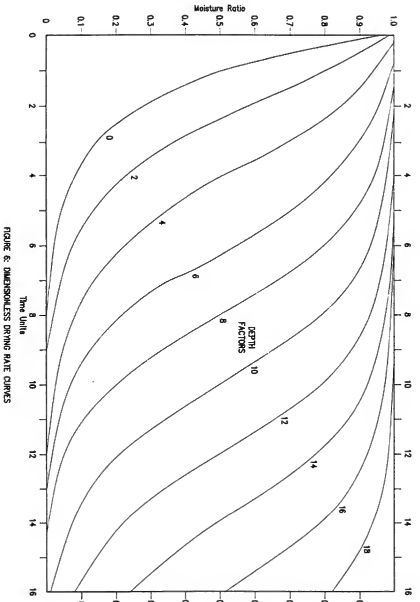
The curves in Figure 5.6 are represented by the equation:

$$\mathbf{MR} = \frac{\mathbf{2^D}}{\mathbf{2^D + 2^Y - 1}}. \tag{8}$$

By transposing the drying conditions to these units and using either Figure 5.6 or Equation 8 it is possible to predict when any layer within the bed reaches a desired moisture content.

More rigorous approaches to the design of drying systems have been developed. These include the methods based on thin layer drying equations described by Brook & Foster (1981)

Figure 5.6. Dimensionless Drying Rate Curves.



and Brooker *et al.* (1974). Many of these have been developed into sophisticated simulation techniques (Brooker *et al.* 1974).

The drying conditions for specific grains and situations are many and varied. Drying will take place under any conditions where grain is exposed to a flow of unsaturated air. Very fast drying can be accomplished using large volumes of high temperature air but, if carried through to completion, is likely to be inefficient in energy use and liable to damage the grain by over-heating and/or over-drying. Conversely slow drying, as in sun drying in inclement weather, provides conditions for continued respiration and deterioration of the grain leading to both quantitative and qualitative losses and the growth of moulds.

Drying Efficiency

The efficiency of the drying operation is an important factor in the assessment and selection of the optimum dryer for a particular task. There are three groups of factors affecting drying efficiency:

* those related to the environment, in particular, ambient air conditions;
* those specific to the crop;
* those specific to the design and operation of the dryer.

There are several different ways of expressing the efficiency of drying, of which the **sensible heat utilization efficiency** (SHUE), the **fuel efficiency**, and the **drying efficiency** are the most useful.

The SHUE takes into account the sensible heat attributable to the condition of the ambient air and any heat added to the air by the fan as well as the heat supplied by combustion of the fuel. It is defined as:

$$\text{SHUE} = \frac{\text{Heat Utilized for Moisture Removal}}{\text{Total Sensible Heat in the Drying Air}} \, .$$

The fuel efficiency is based only on the heat available from the fuel:

$$\text{Fuel Efficiency} = \frac{\text{Heat Utilized for Moisture Removal}}{\text{Heat Supplied from Fuel}}$$

It can be appreciated that the fuel efficiency would be significantly different for the operation of the same dryer at two locations with widely different ambient conditions. With low temperature drying, particularly in dry climates, the heat supplied from the fuel may be less than half of the total sensible heat and the fuel efficiency may exceed 100%. Direct comparison of the performance of dryers at separate locations is not possible using the fuel efficiency.

The drying efficiency, defined as:

$$\text{Drying Efficiency} = \frac{\text{Heat Utilized for Moisture Removal}}{\text{Heat Available for Moisture Removal}},$$

is the expression to be used for evaluation of dryer designs or comparison between dryers, since it is a measurement of the degree of utilization of the sensible heat in the drying air.

Foster (1973) evaluated the fuel and drying efficiencies of several types of dryers used with maize. Over a wide range of conditions, continuous-flow dryers were found to have a fuel efficiency of 38% and a drying efficiency of 51%, batch dryers 42% and 58%, dryeration 61% and 78%, and two-stage drying, 60% and 79%, respectively.

Effect of Drying on Grain Quality

The drying operation must not be considered as merely the removal of moisture since there are many quality factors that can be adversely affected by incorrect selection of drying conditions and equipment. The desirable properties of high-quality grains include:

* low and uniform moisture content;
* minimal proportion of broken and damaged grains;
* low susceptibility to subsequent breakage;
* high viability;
* low mould counts;
* high nutritive value;
* consumer acceptability of appearance and organoleptic properties.

Moisture Content. It is essential that the grain after drying is at a moisture content suitable for storage. As discussed the desired moisture content will depend on the type of grain, duration of storage, and the storage conditions available. It is also important that the drying operation is carried out to minimize the range of moisture levels in a batch of dried grain. Portions of under-dried grain can lead to heating and deterioration.

Stress Cracking and Broken Grains. Drying with heated air or excessive exposure to sun can raise the internal kernel temperature to such a level that the endosperm cracks. The extent of stress cracking is related to the rate of drying. Rapid cooling of grain can also contribute to stress crack development.

Nutritive Value. Grain constituents such as proteins, sugars and gluten may be adversely affected when the grain attains excessive temperatures. The feeding value of grains can be lowered if inadequately dried.

Grain Viability. Seed grain requires a high proportion of individual grains with germination properties. The viability of grain is directly linked to the temperature attained by grains during drying (Kreyger 1972).

Mould Growth. Many changes in grain quality are linked to the growth of moulds and other microorganisms. The rate of development of microorganism is dependent on the grain moisture content, grain temperature, and the degree of physical damage to individual grains. Mould growth causes damage to individual grains resulting in a reduction in value. Under certain circumstances mycotoxin development can be a particular hazard.

Appearance and Organoleptic Properties. The colour and appearance as perceived by the customer and/or consumer. For example, the colour of milled rice can be adversely affected if the paddy is dried with direct heated dryers with poorly maintained or operated burners or furnaces.

NATURAL AND SOLAR DRYING

Sun Drying

The traditional practice of grain drying is to spread crop on the ground, thus exposing it to the effects of sun, wind and rain. The logic of this is inescapable; the sun supplies an appreciable and inexhaustible source of heat to evaporate moisture from the grain, and the velocity of the wind to remove the evaporated moisture is, in many locations, at least the equivalent of the airflow produced in a mechanical dryer. In tropical countries, for at least several months of the year, the mean level of insolation upon the ground is more than 0.5 kW/m^2 (measured as a mean over the hours of daylight). The heat available therefore, assuming a 12 hour day, is 21.6 MJ/m^2, a quantity theoretically sufficient to evaporate 9 kg of water.

Even today, sun drying of grain remains the most common drying method in tropical developing countries. It is first employed when the crop is standing in the field prior to harvest; maize cobs may be left on the standing plant for several weeks after attaining maturity. Although not requiring labour or other inputs field drying may render the grain subject to insect infestation and mould growth, prevent the land being prepared for the next crop and is vulnerable to theft and damage from animals. Drying in the field may also be carried out after harvest with the harvested plants laid in stacks with the grain, maize cobs or panicles raised above the ground and exposed directly to the sun. Data on the drying of paddy in the field has been gathered by Angledette (1962) and Mendoza *et al.* (1982).

Drying on flat exposed surfaces is the most common way of drying grain after harvesting and threshing. For drying small amounts on the farm grain may be spread on any convenient area of land. Contamination with dirt cannot be easily avoided with this method and cleaner dried grain can be obtained by drying the grain on plastic sheets, preferably black.

Purpose-constructed drying floors are commonly used where there is a need to dry large quantities of grain during the season, e.g. at most rice mills. The floors are usually made of concrete or brick, these materials presenting a relatively smooth and hardwearing surface. Floors should be constructed to withstand the movement of vehicles and sloped or channelled

to hasten the runoff of rainwater. The paddy is spread in a thin layer on the floors and raked at intervals, preferably 7-8 times daily, to facilitate even drying. At night the paddy is heaped into rows and covered with sheeting.

Work by Chancellor (1965) and Soetoyo & Soemardi (1979) has demonstrated that paddy can be dried from 24-26% moisture to 14% moisture at depths of 50-100 mm at a rate of 3.3 $kg/m^2.h$ for stirred paddy and 1.9 $kg/m^2.h$ for unstirred paddy. The grain can reach temperatures as high as 60°C under clear skies and the rate of drying can be extremely high. Under these circumstances kernel cracking and loss of head rice can be appreciable, particularly if paddy is dried to below 14% moisture. Covering the paddy around midday may be beneficial under particularly hot and sunny conditions. Experiments at IRRI have shown that cracking can be reduced by 25% if paddy is dried in the shade but the benefit from the improved quality is generally more than offset by the longer drying times and hence reduced throughput and increased costs.

In rainy weather, even though drying will be slow, every effort should be made to prevent wet freshly-harvested paddy from over-heating with deterioration in quality by spreading on floors rather than let it remain in heaps and sacks. Under these conditions or when there is great demand for drying space paddy can be dried to 17-18% moisture and then temporarily stored for 15-30 days before final drying.

Crib Drying

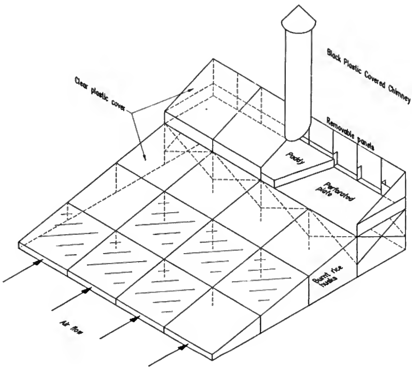
Compared with paddy, cob maize can remain at relatively high moisture contents, in excess of 20% with natural ventilation for considerably longer periods, from one to three months. The maize crib in its many forms acts as both a dryer and a storage structure. The rate and uniformity of drying are controlled by the relative humidity of the air and the ease with which air can pass through the bed of cobs. The degree of movement of air through the loaded crib is largely attributable to the width of the crib; research in West Africa has shown that crib widths should not exceed 0.6 m (Anon 1980). Guide-lines on crib design, construction and operation have been prepared by Bodholt (1985). Further information on crib design is available in Chapter 6.

Solar Dryers

An improved technology in utilizing solar energy for drying grain is the use of solar dryers where the air is heated in a solar collector and then passed through beds of grain. There are two basic types of solar dryer appropriate for use with grain: natural convection dryers where the air flow is induced by thermal gradients; and forced convection dryers wherein air is forced through a solar collector and the grain bed by a fan (Brenndorfer *et al.* 1985).

Natural convection dryers are generally of a size appropriate for on-farm use. A design that has undergone considerable development by the Asian Institute of Technology (AIT) in Bangkok, Thailand (Boothumjinda *et al.* 1983; Exell 1980) is shown in Figure 5.7. The dryer consists of three components, a solar collector, the drying bin and a solar chimney. For a one tonne capacity dryer the collector is 4.5 m long and 7.0 m wide with the solar absorber base of burnt rice husks or black plastic sheet covered with clear plastic sheet. The drying bin is 1.0 m long and 7.0 m wide with a base of perforated steel or bamboo matting.

Figure 5.7. Natural Convection Solar Dryer.



Source: Exell (1980)

The solar chimney provides a column of warm air that increases the thermal draught of air through the dryer. It is made of a bamboo frame covered with black plastic sheet. In Thailand paddy was dried from 20% moisture to 13% moisture in 1-2 days and the rice quality was appreciably greater than that from sun dried paddy. A disadvantage of the dryer is its high structural profile which poses stability problems in windy conditions, and the need to replace the plastic sheet every 1-2 years. A smaller (100 kg capacity) and simpler version of this type of dryer has also been developed (Exell & Kornsakoo 1978; Oosthuizen & Sheriff 1988) as shown in Figure 5.8.

The forced convection solar dryer can be considered as a conventional mechanical drying system in which air is forced through a bed of grain but the air is heated by a flat plate solar collector rather than by more conventional means. Several types of flat plate collector are shown in Figure 5.9.

Figure 5.8. Small scale Solar Paddy Dryer.

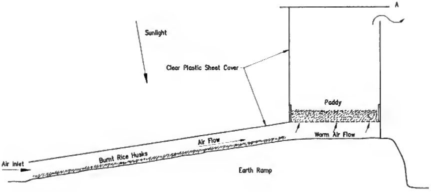


FIGURE 8: SMALL SCALE SOLAR PADDY DRYER (EXELL AND KORNSAKOO 1980)

Source: Exell and Kornsakoo (1980)

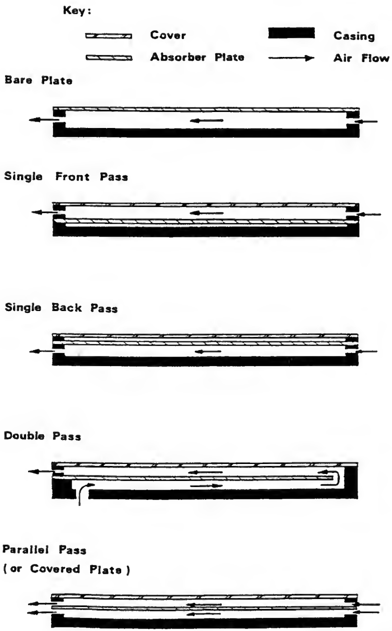
The performance of a flat plate collector can be quantified by calculation of the **collection efficiency**; the ratio of the heat gathered by the collector to the insolation incident on its surface. The collection efficiency is a function of the air velocity through the collector, the geometry of the air duct, the absorptivity of the absorption surface, and the transmissivity of the cover(s).

Considerable work has been undertaken in developing low-cost and efficient solar collectors for crop drying applications (Brenndorfer *et al.* 1985; Davidson 1980). The simplest type of collector is the **bare plate** (Figure 5.9) which consists simply of an air duct the uppermost surface of which acts as the absorber plate. The **covered plate** collector in its many forms utilises a translucent cover above the absorber plate; four versions of this type are also shown in Figure 5.9. Compared with the bare plate collector higher collection efficiencies are obtainable with covered plate collectors but at the expense of increased complexity and cost.

The optimum design suitable for use at farms and mills in developing countries is probably the bare plate collector which is capable of operating at a collection efficiency of 40-50% with an airflow of 0.10 $kg/s.m^2$. With typical insolation levels in many tropical countries of the order of 0.5 kW/m^2 such collectors are capable of providing mean daily elevations in air temperature of 5-10°C with heat outputs of 0.20-0.25 kW/m^2 of collector area. Covered plate collectors, operating at efficiencies of 60-70%, are capable of providing air temperature elevations of 10-30°C but at a lower airflow.

A major advantage of the bare plate collector is that it can be easily incorporated into the roof of a dryer or storage building. Corrugated iron is a popular and inexpensive roofing

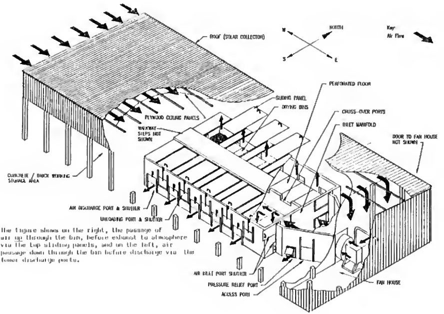
Figure 5.9. Flat Plate Collectors.



material in many areas and when painted black forms an excellent solar absorber. A false ceiling can be fixed to the roof joists so forming a shallow duct running the length of the building and easily connected to a fan via ducting at one end of the building. The heat available from the collector is weather dependent and consideration should therefore be given as to whether solar energy should be the sole source for heating the air or a supplement to more conventional heating systems.

Research and performance studies on forced convection solar dryers have been reported by Bose (1978), Muthuveerappan *et al.* (1978) and Soponronnarit *et al.* (1986). Damardjati *et al.* (1991) have described the performance in Indonesia of a 10 tonne/day paddy dryer (Figure 5.10) that incorporated a 225 m^2 roof-type collector together with a moisture extraction unit (MEU, see below). Heat output from the collector averaged 60 kW over daylight hours and that from the MEU 35 kW with a mean daily elevation in air temperature of 7-9°C.

Figure 5.10. Forced Convection Solar Paddy Dryer.



Source: Damardjati, Trim and Haryano (1991).

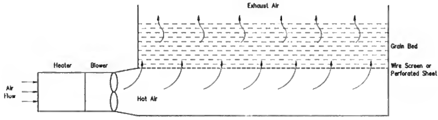
MECHANICAL DRYERS

Batch-in-Bin Dryers

The small capacity version of the batch-in-bin dryer, otherwise known as the **flat-bed dryer**, has been developed for farm- or village-level use. Its capacity is of the order of 1-3 tonnes/day with drying times of 6-12 hours.

As represented in Figure 5.11 the flat-bed dryer is simple to construct using easily available and inexpensive materials and easy to operate with unskilled labour. The walls of the drying bin can be constructed of wood, brick or metal. The floor of the drying chamber is preferably made from fine wire mesh, suitably supported, or perforated metal. If these are not available then sacking spread over a coarser but stronger wire mesh can be used. To facilitate an even airflow through the bed the length of the drying chamber should be 2-3 times the width. The height of the plenum chamber is of the order of 0.3 m. Unloading ports can be fitted at intervals in the walls of the drying chamber.

Figure 5.11. Flat Bed Dryer.



In order to prevent excessive moisture gradients through the bed, the depth of grain in the bin is relatively shallow, 0.4-0.7 m. and the air velocity is usually of the order of 0.08-0.15 m/s for maize and 0.15-0.25 m/s for paddy. The temperature of the air is selected according to the desired safe storage moisture content of the grain. For the drying of paddy in tropical areas an air temperature of 40-45°C is usually used, with a heater capable of raising the air temperature by 10-15°C. With such bed depths and air velocities the pressure drop over the bed is relatively low, 250-500 Pa, and therefore simple and inexpensive axial-flow fans can be used. Typically power requirements are 1.5-2.5 kW per tonne of grain for a belt-driven fan powered by a petrol or diesel engine.

Operation of flat-bed dryers invariably results in a moisture gradient between the lower layers and the higher layers of the bed (Soemangat *et al.* 1973). This problem can be reduced by careful selection of drying temperature and airflow conditions but, even so, gradients of 3-4% moisture are to be expected. Turning of the grain in flat-bed dryers at intervals can alleviate the problem but this extends the drying time and requires additional labour.

The flat-bed dryer is easily loaded from sacks by hand. However, unloading the dried grain into sacks can be time- and labour-consuming; placement of the drying bin on a tilting frame has been investigated (Wimberly 1983) but this incurs additional costs.

Dryers of this type have been developed in many countries and designs are available from the University of the Philippines at Los Baños (UPLB), Los Baños, Philippines and the International Rice Research Institute (IRRI), Manila, Philippines.

IRRI have also developed a vertical batch-in-bin dryer which operates more efficiently than the flat-bed dryer. It differs from the latter in that the airflows horizontally through the bed on either side of the plenum chamber and exhausts through slatted sides. The bin is easily unloaded by removing the slats. Details are available from IRRI.

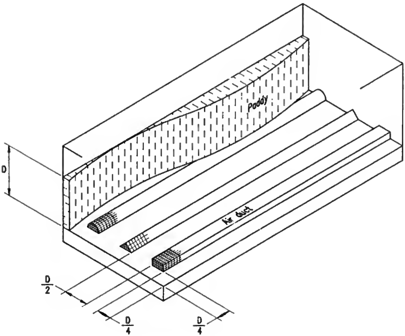
Both direct and indirect heaters can be used with the flat-bed dryer (see below). Solar air heating (see above) can also be an option. The waste heat from the engine used to power the fan can be used (Esmay & Hall 1973; Soemangat *et al.* 1973; Teter 1987). Heating of the air by 5-10°C using waste engine heat is possible but the engine exhaust gases should not be drawn through the grain; the exhaust gases should be ducted outside the housing around the engine. A development of this principle is the **moisture extraction unit** (MEU) in which the fan is directly driven by the engine and the air is drawn over and around the engine block and exhaust pipe.

Large capacity batch-in-bin (or in-store) dryers can be used in cooler dryer areas. The advantage of this technique is that the bin is used for both drying and storage with savings in both capital and operating costs. With heated air at a temperature of 40-45°C, bed depths of 2-3 m can be used with air velocities through the bed not exceeding 0.08 m/s. Since drying times to achieve reductions in moisture content of 5-10% can be of the order of 20-40 days, this method should not be used in humid areas with grain of moisture contents greater than 18% because of the risks of sprouting and mould growth in the upper layers of the bed.

Large batch-in-bin dryers are usually round or rectangular and range in capacity from ten to several hundred tonnes. With large bins, air distribution ducts at the base of the bin are used rather than a plenum chamber. The ducts can be semi-circular, rectangular or triangular as shown in Figure 5.12. To ensure good air distribution through the bed, ducts should be spaced from each other at a distance of half the depth of grain and one quarter the depth from the end and side walls. Air velocity through the ducts should not exceed 5 m/s because of pressure drop factors. More than one fan can be used to provide the airflow required. Detailed information on duct design and airflow distribution is presented by Brooker *et al.* (1974).

In-bin layered drying with ambient air can be performed with confidence in locations where the relative humidity of the air is less than about 70%. An initial layer of grain, 0.6-0.9 m deep, is loaded into a storage bin, 5-10 m deep, and further layers are added as drying proceeds. Over-drying of the grain is minimized because of the low air temperature. In the USA an airflow of 0.025-0.06 m^3/s per tonne was used to dry paddy from 20% moisture to 16% moisture within 14 days when ambient temperature ranged from 18-24°C (Houston 1972). Careful and skilled management is required to ensure that each layer is dried before the succeeding layer is loaded into the bin.

Figure 5.12. Air ducts for large Batch-in-Bin Dryer.



View showing three different forms of Air Duct: Rectangular, Triangular, and Semi-Circular. Dimensions are in relationship to grain depth D.

Some success has been reported in Indonesia for the drying of paddy from 18% moisture to 13% moisture (Gracey 1978; Renwick & Zubaidy 1983). The latter also demonstrated that field-wet paddy (24% moisture) could be dried safely in bulk to 18% moisture by continuous aeration (24 h/day) with ambient air, regardless of the humidity of the air. Subsequent drying to 14% moisture or less was accomplished by drying at times of lesser humidity and with the addition of waste engine heat.

There can be a need to dry grain in sacks in certain instances: for example, at central drying facilities where farmers wish to retain access to their own grain. Stacks of sacks are laid over air distribution ducts with no need for a conventional drying bin. Drying proceeds in much the same manner as for bin drying. After use, the air distribution ducts can be dismantled easily to allow use of the building for other purposes.

Re-circulating Batch Dryers

This type of dryer avoids the problems of moisture gradients experienced with bin dryers by re-circulating the grain during drying. One version of a re-circulating batch dryer is shown in Figure 5.13. The dryer is a self-contained unit with an annular drying chamber, 500 mm thick, around a central plenum chamber, a fan and heater, and a central auger for transporting the grain from the bottom to the top. When drying is complete the grain is discharged from the top. Most dryers of this type are portable and can be moved relatively easily from farm to farm.

Air temperatures of 60-80°C are employed with air flowrates of 0.9-1.6 m^3/s per tonne of grain, twice that used in flat-bed dryers (Wimberly 1983). However, since the grain is only exposed to the flow of hot air for relatively short times within each cycle, too rapid drying rates are avoided and moisture distribution within individual grains is equalised during the period the grain remains in the non-drying sections at the top and bottom of the dryer. Control of the drying rate can be effected by adjusting the auger speed to regulate the flow of grain through the dryer.

Another version of a re-circulating batch dryer is rectangular with drying chambers on either side of the heater, fan and plenum chamber. Under each drying chamber are horizontal screw conveyors that collect the grain and return it to a screw auger at one end that lifts the grain to a holding section at the top. A screw conveyor in the holding section distributes the grain evenly along each drying chamber.

The capital cost of re-circulating batch dryers is considerably greater than batch-in-bin dryers (Table 5.5) because of their greater complexity and incorporation of handling and conveying devices. However, throughput is greater due to the shorter drying times and the quality of the dried grain is likely to be higher. Re-circulating batch dryers require specialist skills for construction and trained operators for successful operation and therefore are not generally suitable for operation by small-scale farmers or enterprises.

Continuous-flow Dryers

Continuous-flow dryers can be considered as an extension of re-circulating batch dryers. However, rather than the grain re-circulating from bottom to top, as in the latter, the grain is removed from the bottom, in some systems, cooled, and then conveyed to tempering or storage bins. In their simplest form continuous-flow dryers have a garner (or holding) bin on top of a tall drying compartment. With some dryers a cooling section is employed below the drying compartment in which ambient air is blown through the grain. At the bottom of the dryer is the flow control section that regulates both the circulation of grain through the dryer and its discharge.

Figure 5.13. Re-circulating Batch Dryer.

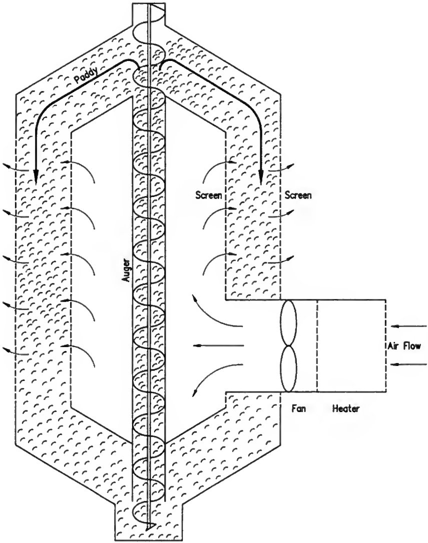


Table 5.5. Dryer Specifications, Estimated Performance, and Cost for drying Freshly Harvested Field Paddy (Raw Paddy) from 20% to 14% Moisture

	Batch-in-bin		Recirculating batch		Continuous-flow	
	Small	Large	Small	Large	Small	Large
Dryer Specifications						
Capacity (t)	2	100	5	10	5-10	10-25
Approximate Power Consumption (hp)	3	10	15	25	15-20	25-50
Approximate Air Flow (m^3/s per tonne)	50	23	56-85	70-100	85-115	115-140
Approximate Drying Air Temperature (°C)	43	43	60-80	60-80	60-80	60-80
Approximate Burner Capacity (kW)	30	1,200	600	1,200	1,200	2,400
Estimated performance						
Drying Capacity (t/day) from 20% to 15% moisture	6	10	15	30	60	100
Annual Drying Capacity (tonnes) (40 days/year operation)	240	400	600	1,200	2,400	4,100
Estimated Cost* (US$)						
Investment, Drying Equipment only	800	6,000	15000	24,000	40,000	50,000
Annual Fixed Cost	240	1,800	4,500	7,200	12,000	15,000
Annual Variable Cost	720	1,200	1,800	3,600	7,200	12,000
Annual Total Cost	960	3,000	6,300	10,800	19,200	27,000
Cost/tonne	4.0	7.50	10.50	9.0	8.0	6.75

* Based on 1978 price data.

Source : Wimberly (1983)

There are three categories of continuous-flow dryers based on the way in which grain is exposed to the drying air:

* **crossflow**, in which the grain moves downward in a column between two perforated metal sheets while the air is forced through the grain horizontally. Dryers of this type are relatively simple and inexpensive, but, unless mixing systems are incorporated, moisture gradients are set up across the bed;

* **counterflow**, which employs a round bin with an unloading system at the base and an upward air flow. These dryers are relatively efficient since the air exhausts through the wettest grain. Bed depths of up to 3-4 m can be used;

* **concurrent flow**, which is the reverse of counterflow drying in that the air moves down through the bed. High air temperatures can be used since the air first comes into contact with wet, and sometimes cold, grain. Drying is rapid in the upper layers but slower at the bottom with some tempering action. Bed depths of at least a metre are used;

Probably the most commonly used continuous-flow dryer is the crossflow columnar dryer, which can be classified as **non-mixing** and **mixing** types.

In one version of a non-mixing dryer (Figure 5.14), drying takes place between two parallel screens, 150-250 mm apart on either side of the plenum chamber. The air escapes from the dryer through louvres on either side of the dryer. The flow rate of grain through the dryer is controlled by a regulator gate at the base of the drying column. Since the grain flows plug-like through the drying section the layer of grain closer to the plenum chamber is dried by hotter and drier air than is the grain on the outside. However, mixing is effected to a fair degree when the grain is discharged and conveyed to tempering and storage bins. Air temperatures of 45-55°C and airflows of 2-4 m^3/s per tonne of grain are used. Flow problems can be encountered with very wet and dirty grain as the grain may clog. Teter (1987) notes that if very wet paddy is to be dried then the grain should be cleaned and also pre-dried to at least 22% moisture before a non-mixing dryer can be used.

In one design of the mixing type of continuous-flow dryer, as also shown in Figure 5.14, a baffle system facilitates the mixing of grain and avoids the development of moisture gradients across the drying bed. Higher air temperatures, 60-70°C, can therefore be used without damaging the grain. Unless screens are fitted on the outside of the drying section lower airflows, 1-1.5 m^3/s per tonne of grain, have to be used to avoid grain being blown out of the dryer.

Another design of this type is the LSU (Louisiana State University) dryer (Figure 5.15). In this version the drying section consists of a vertical compartment across which rows of air channels are installed. One end of each channel is open and the other closed. Alternative rows are open to the plenum chamber and intervening rows to the exhaust section. Alternate rows are also offset such that the channel tops divide the moving stream of grain as it descends providing considerable mixing.

Figure 5.14. Continuous Flow Dryers.

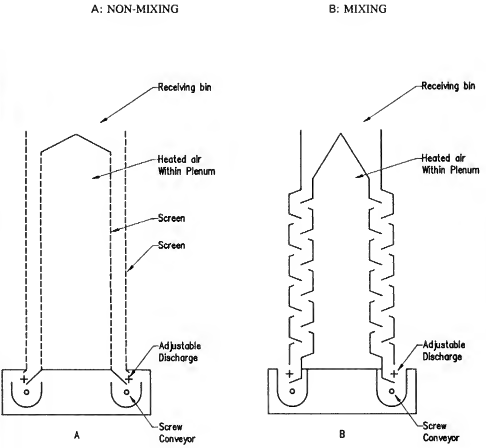
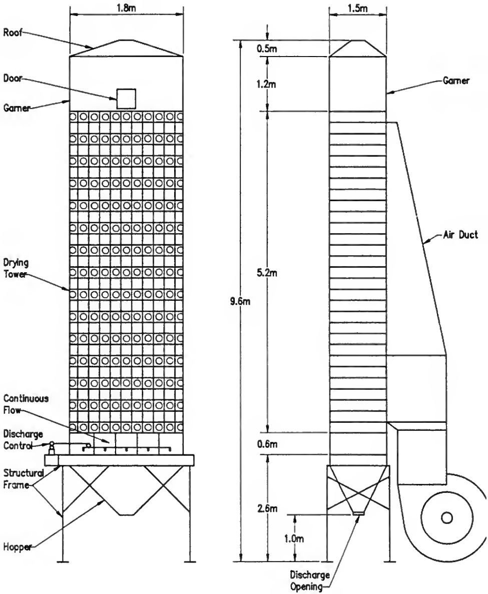


Figure 5.15. Louisiana State University (LSU) Continuous Flow Dryer.



Further information on continuous-flow dryers has been presented by Bakker-Arkema *et al.* (1982), Fontana *et al.* (1982) and Houston (1972). As can be appreciated from Figure 5.14 many of these dryers are large and complex structures and are usually designed and constructed by specialist firms.

Compared with batch-in-bin dryers and re-circulating batch dryers, continuous-flow dryers offer the largest drying capacity. When large volumes of wet grain are to be dried in a single site these are the types to be considered first. They are most commonly used in a multi-pass drying operation as shown in Figure 5.16. Investment costs are high (Table 5.5) but because of the large throughputs operating costs per tonne can be lower than the larger batch-in-bin dryers and re-circulating dryers.

In a multi-pass drying system, continuous-flow dryers are used in association with tempering bins. During each pass through the dryer the grain is dried for 15-30 minutes with a reduction in moisture content of 1-3%. Drying at this rate sets up moisture gradients within the individual grains. After each pass the grain is held in a tempering bin where the moisture within the kernel equalises as moisture diffuses from the interior of each kernel to the surface. The combination of rapid drying and tempering is repeated until the desired moisture content is attained. Using this procedure the actual residence time of the grain within the continuous-flow dryer is of the order of 2-3 hours to effect a 10% reduction in moisture. Selection of the number of passes is a compromise between the dryer efficiency, ie fewer passes, and grain quality, ie longer drying time. Tempering periods are usually 4-24 hours in duration. The tempering bins may be aerated with ambient air to cool the grain with some slight moisture removal.

It is vital that the operation of drying with tempering is carefully planned and managed to ensure maximum throughput and efficiency. This usually means that the plant is operated 24 hours a day with two or more batches of grain being dried at a time. Well trained management and staff are essential.

DRYING OPERATIONS

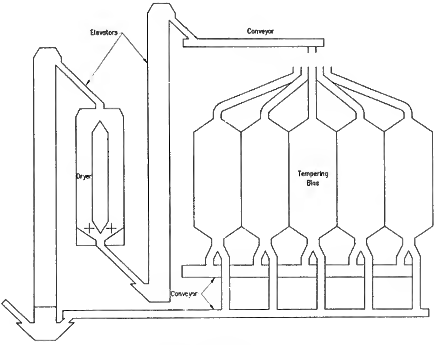
Dryeration

Originally developed for use with maize, dryeration is a combination of heated air drying and aeration cooling. In this process a tempering period is employed between a high temperature drying phase and a cooling phase. Whereas less than 1% moisture is removed if cooling is carried out immediately after drying, as much as 2% moisture can be removed if the grain is cooled slowly after tempering. Damage to the grain is reduced and drying efficiency is improved through better utilization of the residual heat in the grain for moisture removal during cooling. Higher air temperatures can be used in the drying phase since the grain is not dried to such a low moisture content.

Two-Stage Drying

Two-stage or combination drying can be used to relieve pressure on drying facilities during peak periods. For example, paddy at moisture contents of less than 18% can be stored for up to 20 days without significant losses either in quantity or quality. In two-stage drying,

Figure 5.16. Large drying system using Continuous-flow Dryer, Conveying Equipment, and Tempering Bins.



Source: Wimberley (1983).

grain is dried to an intermediate moisture content, 20% moisture for maize, 18% moisture for paddy, as soon as possible using any of the methods described above and then dried in-store to the desired final moisture content over several days or weeks with intermittent use of ambient air or air heated by 3-5°C. Research with paddy in the Philippines (Tumambing & Bulaong 1986; Adamczak *et al.* 1986) has shown that, in addition to increasing throughput of the first stage dryers, there were substantial overall energy savings and no loss of quality compared to drying to 14% moisture in the conventional manner.

Pre-drying Aeration

Work in the Philippines has shown that wet paddy can be maintained in reasonable condition for 3-7 days when aerated with ambient air (Raspusas *et al.* 1978; de Castro *et al.* 1980). By aerating stacks of sacked paddy at a rate of 0.5 m^3/s per tonne for eight hours a day, quality could be maintained for nine days during the dry season and two days during the wet season. Aerating in bulk with similar airflows maintained quality for 14 days and three days

respectively (Raspusas *et al.* 1978). The length of time that paddy can remain in aerated storage without deterioration is dependent on the moisture content of the grain and ambient air conditions.

Drying of Parboiled Paddy

After parboiling, paddy contains about 35% moisture. During the parboiling process the starch is gelatinized which confers quite different drying properties to that of field paddy. It has been shown (Bhattacharya & Indudhara Swamy 1967) that in the drying of parboiled paddy, significant damage (ie kernel cracking) does not occur until the moisture content falls to 16%, regardless of the drying method or the rate of drying,. Cracking then occurs some time after the grain has cooled. The recommended drying procedure is to dry the parboiled paddy to 16-18% moisture as fast as facilities permit, temper it for four hours if warm or eight hours if cooled, and then dry in a second operation to 14% moisture. Air temperatures of 100-120°C can be used for parboiled paddy in continuous-flow dryers.

Drying of Seed Grain

If grain is destined for use as seed then it must be dried in a manner that preserves the viability of the seed. Seed embryos are killed by temperatures greater than 40-42°C and therefore low temperature drying regimes must be used. Seed grain may be dried in any type of dryer provided that it is operated at a low temperature and preferably with greater air flowrates than generally used. It is essential that batches of grain of different varieties are not mixed in any way and therefore the dryers and associated equipment used must be designed for easy cleaning. In this respect simple flat-bed dryers are more suitable than continuous-flow dryers.

Teter (1987) noted that seed paddy can be sun dried at depths of up to 30 mm but that the final stages of drying to 12% moisture should be conducted in the shade to avoid overheating and kernel cracking. Flat-bed dryers can be used with bed depths of up to 0.3 m, air temperatures not exceeding 40°C, and airflows of 1.3-1.7 m^3/s per tonne of grain.

Cross-mixing between batches of different varieties can be avoided by drying in sacks in a flat-bed dryer although care must be taken in packing the loaded sacks in the dryer to ensure reasonably even distribution of airflow. Specialised tunnel dryers in which sacks or portable bins are individually placed over openings in the top of the tunnel have been developed (Teter 1987).

NOVEL DRYERS AND RECENT DEVELOPMENTS

Fluid Bed Drying

This type of dryer in which individual grains are suspended and sometimes transported by air moving at high velocity, 2-3 m/s, can produce very evenly dried grain. Recent research in the Philippines (Sutherland & Ghaly 1990; Tumambing & Driscoll 1991) has indicated that the fluid bed dryer has promising potential for the rapid first-stage drying of paddy to 18% moisture in two-stage drying (see above). Paddy at a bed depth of 100 mm can be dried from 24% to 18% moisture in 15 minutes with air at 100°C and a velocity of 2 m/s, with

no adverse effects on quality. However, due to the high air velocities required to fluidise the paddy, power requirements for the fan are high and the thermal efficiency is low compared to conventional (fixed bed) drying. Re-cycling of the exhaust air was identified as a potential means to improve the thermal efficiency.

Conduction Drying

Work at IRRI (Stickney *et al.* 1983) has investigated the use of a heated floor dryer. This consisted of a metal floor heated to 50-90°C by circulation of water heated by a furnace burning agricultural wastes. Paddy at depths of up to 60 mm could be dried from 22-26% moisture to 18% moisture in 1-2 hours depending on the floor temperature. Frequent raking was necessary but no parboiling effects were recorded and grain breakage was generally lower than that of sun dried paddy. This method is also considered as an option for the first- (rapid-drying) stage of two-stage drying.

The Warehouse Dryer

This dryer has been developed (Jeon *et al.* 1984) for use with a wide range of crops including maize and paddy. Its particular feature is the use of a wind-powered vortex flow inducer as an alternative to conventionally powered fans for generating increased airflow over and around the drying grain. The flow inducer is mounted centrally on the roof of the dryer building and draws air, heated by a furnace and heat exchanger, through the drying bins or trays positioned in the middle of the dryer. The performance is governed by the velocity of the prevailing wind.

Rotary Drying

This method of drying has been researched at the IRRI in Philippines and also at the AIT in Thailand. Small dryers for farm use were developed at the IRRI as reported by Espanto *et al.* (1985). A directly-heated version consists of a perforated iron drum (0.6 m in diameter and 0.9 m long) mounted over a portable stove. The interior of the drum is fitted with flights to facilitate mixing and uniform heat transfer. The drum is rotated manually.

An indirect-heated dryer is constructed from a 200 l oil drum also mounted over a stove. Air is passed through the drum by a fan.

The performance of both dryers was very similar. Batches of 25 kg of paddy at 28% moisture can be dried to 18% moisture in 50-60 minutes and batches of maize from 33% moisture to 18% moisture in 80 minutes. Larger versions of the indirectly- heated dryer have been built (Jeon *et al.* 1990). With paddy, milling quality was improved relative to sun drying but the viability of the grain was greatly reduced due to the high temperatures attained at the drum surface. Similar results were obtained with the AIT dryer as reported by Jindal & Obaldo (1986).

Microwave and Infrared Dryers

When grain is irradiated by electromagnetic energy high temperature potentials are generated between the interior and surface of individual grains. Moisture therefore migrates to the

surface where it evaporates to the surrounding air. The rate of airflow necessary is that required to absorb the moisture and not as the provider of latent heat. This reduction in airflow would minimize the dust and other pollutants discharged to atmosphere. More uniform drying is possible compared with conventional heated-air drying. However the capital cost and energy consumption of the microwave equipment necessary is considerable. Radajewski *et al.* (1988), in Australia investigated, using simulation techniques, the use of microwave heating as a means of pre-heating wheat before drying and concluded that the reduction in drying time could not offset the power consumption required for microwave heating. Infrared heating systems are similarly expensive, and since infrared radiation only penetrates superficially it is necessary to agitate the grain thereby exposing all the surface area to the radiation, thereby incurring additional cost.

ANCILLARY EQUIPMENT

Air Movement

The selection and sizing of a fan to move air through a dryer is very important. The major resistance to the flow of air comes from the grain bed; the pressure drop through the bed support and ducting is of lesser effect, particularly for deep beds. The pressure drop across a grain bed is a function of the depth, the air velocity and the grain itself. Data such as those in Figure 5.4 should be used to evaluate the pressure drop across the grain bed for a given application. It is important to note the major effect of dockage upon the pressure drop generated.

For most situations either **axial-flow** or **centrifugal** fans are used. The axial-flow fan moves air parallel to its axis and at right angles to the field of rotation of its blades. With the centrifugal fan the air enters parallel to the drive shaft, moves radially through the blades and is discharged tangentially from the housing surrounding the impeller. Axial-flow fans can be easily mounted in-line in the ducting and are relatively inexpensive but are only capable of operation against pressure drops of less than 1,500 Pa. Compared with axial-flow fans centrifugal fans can operate against higher pressure drops and are quieter in use but are more expensive.

Brooker *et al.* (1974) provide comprehensive information on the selection and operation of fans. It should be noted, particularly for large-scale dryers containing perhaps hundreds of tonnes of grain, that the risks of mechanical or electrical failure of the fan is likely to result in considerable losses if the fan cannot be repaired within a day or two. Consideration should be given therefore to installation of a back-up fan, particularly in locations where repair facilities are limited.

Air Heating

Heaters can be divided into two types, direct and indirect. In direct heaters the fuel is burnt *in situ* with the drying air so that the products of combustion pass through the drying bed with the air. Heaters of this type are less expensive and more energy efficient; however, the quality of the grain may be lowered due to contamination with combustion products, particularly if the heater is poorly maintained. In indirect heaters the combustion air does not come into contact with the drying air and a heat exchanger is used to raise the

temperature of the latter. Depending on the type of heat exchanger as much as 25% of the heat may be lost; however, there is no danger of contamination of the grain.

Air for drying can be heated by gas and oil and also solid fuels such as coal, wood and biomass residues. Oil-fired heaters are the most common for use with small on-farm dryers. Oil-fired and gas-fired heaters for all sizes of dryers are commercially available as described by Araullo *et al.* (1976), Brooker *et al.*(1974) and Wimberly (1983). Small heaters are usually transportable and are easily positioned on the suction side of the fan so that the hot air from the heater is drawn into the plenum chamber by the fan together with ambient air.

Use of Biomass

Oil and gas are the conventional fuels employed in heated-air dryers, particularly so for small-scale operations such as the batch-in-bin dryer. The use of these fossil fuels is increasingly expensive and environmentally undesirable. The use of alternative and renewable energy sources is likely become increasingly common as new combustion technologies are developed and conventional fuels increase in cost. In many areas the residues available from grain crops, such as maize cobs and rice husks, are available in large quantities, but are generally under-utilized and present problems of disposal. Depending on the crop production systems employed other agricultural residues may be produced in the vicinity of grain drying plants and may offer alternative fuel options.

Few comprehensive measurements have been made of biomass residue availability. However, estimates have been made from the ratio of crop yield to the residue, data for which is shown in Table 5.6. The estimated world-wide production of agricultural residues (calculated from the crop to residue ratio) is given in Table 5.7. Much of this material has current or potential use for a wide range of applications, but in many places there are under-utilized resources that could be used as fuel for grain drying. Table 5.8 provides details of calorific values of a selection of agricultural residues and wood.

There are many different combustion systems that are currently or potentially suitable for combustion of biomass residues. The broad classification of types of combustion systems and their status of development is outlined below (Page 126 *et seq.*).

Table 5.6. Conversion Ratios for the estimation of Crop Residues.

Crop	Residue	Crop : Residue Ratio	Source
Barley	Straw	1 : 1.2	1
Coconut	Shell	1 : 0.15	2
Cotton	Stalk	1 : 4.25	3
Groundnut	Shell	1 : 0.5	3
	Straw	1 : 2.3	3
Jute	Stick	1 : 2.0	3
Maize	Straw	1 : 1.0	1
	Cob	1 : 0.18	4
Millet	Straw	1 : 1.4	1
Oats	Straw	1 : 1.3	1
Palm Kernel	Shell	1 : 0.35	6
Rice Paddy	Husk	1 : 0.22	5
Rye	Straw	1 : 1.6	1
Sorghum	Straw	1 : 1.4	1
Soya beans	Straw	1 : 1.1	5
Sugar Cane	Bagasse	1 : 0.2	5
Wheat	Straw	1 : 1.3	1

Sources: **1**: Hall & Overend (1987); **2**: NRI (unpublished data); **3**: Kristoferson & Bokalders (1986); **4**: Watson & Ranstad (1987); **5**: FAO (1982); **6**: Cornelius (1983).

Table 5.7. Estimated Crop Residue Production of Developing Countries (1989).

Crop	Production '000,000 tonnes	Residue	Production '000,000 tonnes
Barley	24.4	Straw	29.3
Coconut	42.1	Shell	6.3
Cotton	11.7	Stalk	49.8
Groundnut	21.2	Shell	10.6
		Straw	40.5
Jute	3.6	Stick	7.2
Maize	197.7	Straw	197.7
		Cob	35.6
Millet	25.9	Straw	36.2
Oats	2.3	Straw	3.0
Palm Kernel	3.5	Shell	1.2
Rice Paddy	492.6	Husk	108.4
Rye	1.3	Straw	2.1
Sorghum	41.6	Straw	58.6
Soya beans	50.5	Straw	55.6
Sugar cane	962.9	Bagasse	192.6
Wheat	230.7	Straw	299.9

Residue Production from Table 5.6. Source: FAO (1990)

Table 5.8. Alternative uses of Crop Residues.

Material	Gross Calorific Value (daf*) MJ/kg
Alfalfa straw	18.4
Cotton seed husks	19.4
Cotton stalks	17.4
Groundnut shells	19.7
Maize stalks	18.2
Maize cobs	18.9
Rice straw	15.2
Rice husks	15.5
Soybean stalks	19.4
Sugar cane bagasse	19.0
Sorghum bagasse	18.9
Wheat straw	18.9
Wood	20.0

* dry ash free Sources: various

Grate Furnaces. The use of grates is probably the most commonly used method world-wide. There are grate systems suitable for burning a wide range of biomass materials, including many particulate residues and straw. The grate is designed to support the biomass fuel and allow air to circulate freely through it. There are many types of this system: flat grates, both static and moving; cone grates; step grates and sloping grates (Sarwar *et,al.*, 1992). Flat grates (Figure 5.17) are the simplest type and are found in the majority of log and straw burning systems. Step grates (Figure 5.18) are often used to burn rice husks.

Figure 5.17. Flat Grate Furnace.

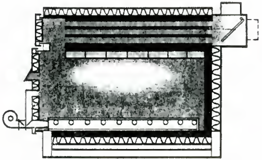
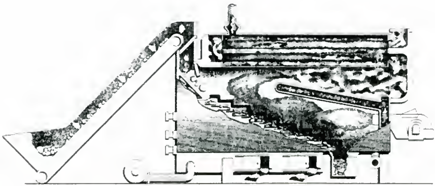
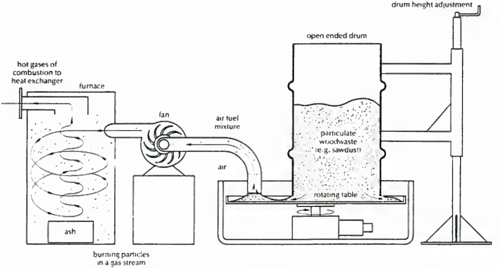


Figure 5.18. Step Grate Furnace.



Suspension Burners. These are suitable to burn particulate agricultural residues of regular size and shape. The systems typically comprise a cylindrical chamber where the combustion air is introduced tangentially as illustrated in Figure 5.19. These systems have great potential for application in developing countries. A small number of commercial and piloted systems exist (Mahin 1991; Robinson 1991).

Figure 5.19. Sawdust fed Suspension Burner, showing connection between furnace and table feeder.



Fluidized Bed Systems. These systems are especially suited for burning both large and small particulate agricultural residues of relatively high moisture contents. The fluidized bed furnace comprises a combustion chamber containing a sand bed acting as the heat transfer medium. Commercial units are generally large-scale and capital intensive and as such are less suited for application in developing countries.

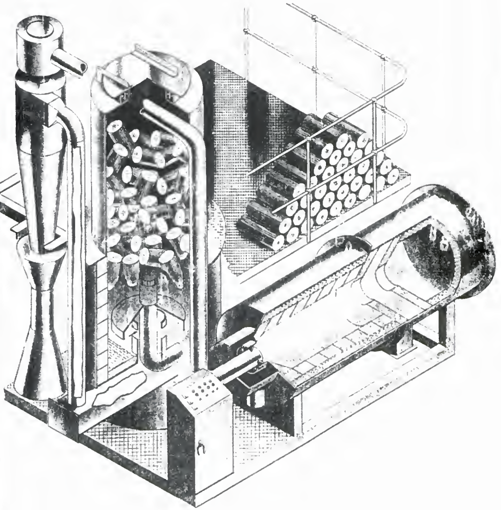
Under-fed Stokers. These systems are also suitable for particulate biomass residues of relatively high moisture content. The biomass is transported by a screw-feeder through a specially constructed trough into the middle of the furnace. From the sides of the trough primary air is forced through the biomass mound. Secondary air is introduced near the top of the mound allowing complete fuel combustion. There has been relatively little application of under-fed stokers in developing countries.

Gasification Systems. These systems can be designed to burn wood in the form of logs (Figure 5.20) and also particulate fuels. The biomass is pyrolysed to produce combustible gases and wood tars. These products of pyrolysis are then used as a fuel. Since good combustion control can be obtained with gasifiers the hot gases of combustion can be employed to direct-fired dryers. Gasifications systems are typically at the experimental or adaptive research and development stage although there has been some limited commercial success with wood and charcoal gasifiers (Breag & Chittenden 1979; Hollingdale 1983; Sarwar *et al.* 1992).

There are handling and combustion advantages in compressing particulate materials into a more compact form, **briquettes**, for use in existing furnace systems (Smith *et al.* 1983). Various techniques can be used for converting residues to briquettes; the piston press, the screw press, the pellet press and the manual press. The experience of briquetting agricultural residues has been mixed. Various technical problems have been encountered but the main difficulty has been the fact that, in many places, briquettes are too high in cost to compete with existing woodfuel (Eriksson & Prior 1990).

Details of the commercial availability of equipment for combustion and handling of biomass materials can be found in publications by Eriksson & Prior (1990), Sarwar *et al.* (1992),and the *Biomass Energy Directory* (Anon. 1992). A great deal of information and consideration is needed to arrive at any reasonable conclusion on the suitability of a particular combustion system for use in grain drying systems in developing countries. A list of principal organizations involved in research activities on biomass residue combustion is given in Annex 2.

Figure 5.20. Gasifier.



Source: Sarwar *et al* (1992).

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CHAPTER 6

STORAGE AT FARM/VILLAGE LEVEL AND IN WAREHOUSES

INTRODUCTION

In this chapter traditional methods of storing grain at producer level and in entrepreneurial warehouses are briefly reviewed. The greater part of the chapter is devoted to describing 'improvements' or developments of grain storage at these levels.

It is often stressed that traditional storage methods are the product of decades, if not centuries of development, perhaps by trial and error, but certainly as a result of experience of the users and their ancestors. This maxim must, in general, be upheld as true and would-be 'developers' should employ utmost respect for traditional practices when endeavouring to introduce 'improvements'. Traditional storage methods at producer level are usually well adapted to both the types of grain for which they are intended, and the environment in which they are employed. Consequently, storage losses are often already minimal and it is difficult to justify interference with the established system.

However, for a number of reasons, this is not always the case. In the first instance, it is well known that rural communities are very conservative in their attitude towards change. Thus, if such a community is uprooted, perhaps as a result of conflict, and is forced to move into an environment which is very different both climatically and geographically from that to which they are accustomed, it may take them a long time to adapt or change their grain storage practices accordingly. This is almost certainly the case in central and eastern parts of Zambia (author's personal experience), where the 'traditional' basket type of store is not the best form of grain container for local climatic conditions[1].

Secondly, a growing shortage of the materials traditionally used for the construction of grain stores (usually caused by extended use of such materials) may force rural people to seek alternative means of storing grain. This is the case in the Anatolia region of Turkey, and in Lesotho where ancient grain storage practices have virtually disappeared, because of the depletion of supplies of suitable timber and/or grass.

Thirdly, but by no means unimportant, the introduction of high-yielding varieties of grain

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[1] Most of Zambia enjoys 8 months of virtually dry weather every year; during which the grain is harvested, dried and stored. In the Southern Province and neighbouring Zimbabwe and Botswana, maize is commonly shelled and stored in mud-plastered bins, in which the relatively pest-free grain remains dry (at or below 12% moisture content) throughout the 4-month long rainy season.

It is believed that the basket-type of store ("nkhokwe") was brought into Zambia from the wetter north (western Tanzania and adjacent areas, where it is a most appropriate form of storage.

(which are usually more susceptible to infestation by insects than traditional varieties) and the spread of exotic insect pests of grain (e.g. *Prostephanus truncatus*) through trade or aid have disrupted erstwhile effective storage practices, to the extent that they have had to be abandoned or at least considerably modified with outside assistance.

Traditional grain traders throughout the world have tended to depend upon fairly rapid turnover of stocks as a means of minimising losses due to pests and other factors. Consequently, their storage facilities vary in quality and condition. With the advent of Government intervention and the establishment of quasi-government grain marketing organizations in many countries, especially during and immediately after the Second World War, the importance of good grain storage facilities and management became apparent. Most of the 'improvements' in warehouse design are associated with such enterprises. The recent tendency to revert to private grain marketing and storage has high-lighted the need for improving the standards of storing and managing grain stocks at this level. Hopefully, the suggestions and recommendations for improving warehouses given in this chapter will help in this regard.

TRADITIONAL FARM/VILLAGE STORAGE METHODS

Temporary Storage Methods

Such methods are quite often associated with the drying of the crop, and are primarily intended to serve this purpose. They assume the function of storage only if the grain is kept in place beyond the drying period.

(i) Aerial Storage (Ref: FAO,1987, fig.6(a))

Maize cobs, sorghum or millet panicles are sometimes tied in bundles, which are then suspended from tree branches, posts, or tight lines, on or inside the house (Figure 6.1). This precarious method of storage is not suitable for very small or very large quantities and does not provide protection against the weather (if outside), insects, rodents, or thieves.

(ii) Storage on the ground, or on drying floors

This method can only be provisional since the grain is exposed to all pests, including domestic animals, and the weather. Usually it is resorted to only if the producer is compelled to attend to some other task, or lacks means for transporting the grain to the homestead.

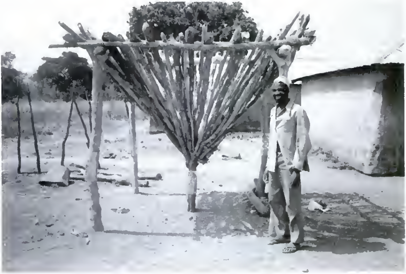
(iii) Open Timber Platforms

A platform consists essentially of a number of relatively straight poles laid horizontally on a series of upright posts. If the platform is constructed inside a building, it may be raised just 35-40 cm above ground level to facilitate cleaning and inspection. Platforms in the open may be raised at least 1 metre above ground level. They are usually rectangular in shape, but circular or polygonal platforms are common in some countries.

Figure 6.1. Maize cobs suspended in trees.

Source: FAO (1987)

Figure 6.2. Inverted cone structure.



Source: Picard?

Grain is stored on platforms in heaps, in woven baskets or in bags. In humid countries fires may be lit under elevated platforms, to dry the produce and deter insects or other pests.

Instead of being horizontal and flat, the platform may be conical in shape, the point at the bottom. Up to 3 metres in diameter, such platforms facilitate drying because of their funnel shape: at the top they consist of a frame of horizontal poles which is square, circular or polygonal in shape, against which the timbers which form the cone rest; these timbers meet at the bottom on a wide central supporting post (Figure 6.2).

Platforms with roofs (but no walls), of whatever shape or form, may be regarded as transitional types between temporary and long-term stores. In southern Benin, Togo and Ghana, for example, maize cobs in their sheaths are laid in layers on circular platforms with their tips pointing inwards. The platforms are usually between 2 and 3 metres in diameter, but some may be more than 6 metres wide, with a maximum height of 2.5 metres at the centre and 1.5 metres at the periphery. In Ghana such a granary is called an "ewe" barn (Figure 6.3).

Long-term Storage Methods

(i) Storage baskets (cribs) made exclusively of plant materials

In humid countries, where grain cannot be dried adequately prior to storage and needs to be kept well ventilated during the storage period, traditional granaries (cribs) are usually constructed entirely out of locally available plant materials: timber, reeds, bamboo, etc. (Figure 6.4.). Under prevailing climatic conditions most plant material rot fairly quickly, and most cribs have to be replaced every two or three years - although bamboo structures may last up to 15 years, with careful maintenance.

Basically similar to the outdoor type of platform described above, in all its variations, the traditional crib differs in always having a roof and wall(s). It may even be elevated at least one metre above ground level, with a fire maintained underneath to assist drying of the contents and, allegedly, to reduce insect infestation. However, such cribs (especially the larger ones) are more commonly raised only 40 to 50 cm above ground level.

Access to the interior of a crib is gained usually over the wall. This may involve raising the roof, but some cribs have a gap between the top of the wall and the roof to facilitate entry. Relatively few cribs have sealable gaps in the wall or floor for the removal of grain.

(ii) Calabashes, gourds, earthenware pots

These small capacity containers are most commonly used for storing seed and pulse grains, such as cowpeas. Having a small opening, they can be made hermetic, by sealing the walls inside and out with liquid clay and closing the mouth with stiff clay, cow dung, or a wooden (cork?) bung reinforced with cloth.

If the grain is dry (less than 12% moisture content) there there is usually no problem with this kind of storage.

Figure 6.3. "Ewe" barn in Ghana.

Source: FAO (1987)

Figure 6.4. Traditional storage crib constructed entirely of plant materials.

Source: FAO (1987)

(iii) Jars

These are large clay receptacles whose shape and capacity vary from place to place. The upper part is narrow and is closed with a flat stone or a clay lid: which is sealed in position with clay or other suitable material. Generally kept in dwellings, they serve equally for storing seeds and legumes. So that they may remain in good servicable condition, they should not be exposed to the sun and should not be either porous or cracked.

(iv) Solid wall bins

Such grain stores are usually associated with dry climatic conditions, under which it is possible to reduce the moisture content of the harvested grain to a satisfactory level simply by sun-drying it. Solid wall bins are therefore traditional in the Sahel region of Africa, and in southern African countries bordering on the Kalahari desert.

The base of a solid wall bin may be made of timber (an increasingly scarce resource), earth or stone. Earth is not recommended because it permits termites and rodents to enter. The better base is made of stone.

Mud or clay silos are usually round or cylindrical in shape, depending on the materials used (Figure 6.5). Rectangular-shaped bins of this type are less common, because the uneven pressure of the grain inside causes cracking - especially at the corners. Clay, which is the basic material, varies in composition from one place to another. That most commonly used for such construction work is obtained from termitaries, because the termites add a secretion which gives it better plasticity. To give it added strength, certain straw materials such as rice straw may be mixed with it; while, in some countries, néré juice is added to make it almost as durable as concrete. The diversity of materials used explains why the capacities of such silos can vary from 150 kg to 10 tonnes.

In West Africa, when only clay is used, the walls are 15 to 20 cm thick: the shape is then more or less cylindrical and the construction is similar to the walls of a house. However, when the clay is strengthened as described above, the bin is usually rounder in shape and resembles a jar; with walls only 2.5 to 5 cm thick, but very strong, so that it is possible to climb on top to enter the silo for regular withdrawal of grain. The interior is often compartmented by vertical internal walls, joining at the centre on a central column which serves to support the foot when one enters the silo. The walls are rendered as smooth as possible, inside and out in such a way as not to offer refuge for insects and their larvae; fissures are sealed with liquid clay before each loading. Similarly, the angles formed by the internal partition walls and external wall are rounded for the same reasons.

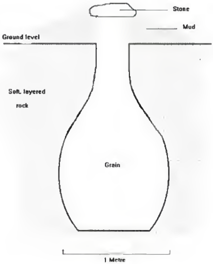
In southern Africa, where the bins are commonly rectangular in plan, internal compartments are usually covered with mud-plastered timber ceilings and are accessed via sealable 'windows'. These face a short corridor leading to the exit, which may be fitted with a standard lockable door.

The roof is usually made of thatched grass, with a generous overhang to protect the mud wall(s) from erosion. Where a side door or a detachable 'cap' is not provided, the roof has to be lifted for access to the bin. Such silos can serve for 30 or even 50 years.

Figure 6.5. Solid wall bin.
The base of this bin houses chickens, which eat termites and thus help to preserve it (!).

Source: Picard?

Figure 6.6. Vertical section of a Cyprus village underground grain store.



Drawn by D L Proctor, after Hall *et al* (1956)

(v) Underground Storage

Practised in India, Turkey, sahelian countries and southern Africa, this method of storage is used in dry regions where the water table does not endanger the contents. Conceived for long term storage, pits vary in capacity (from a few hundred kilogrammes to 200 tonnes). Their traditional form varies from region to region: they are usually cylindrical, spherical or amphoric in shape, but other types are known (Gilman and Boxall, 1974). The entrance to the pit may be closed either by heaping earth or sand onto a timber cover, or by a stone sealed with mud (Figure 6.6).

The advantages of this method of storage are:

- few problems with rodents and insects;
- low cost of construction compared to that of above-ground storage of similar capacity;
- ambient temperatures are relatively low and constant;
- hardly visible, and therefore relatively safe from thieves;
- no need for continuous inspection.

The disadvantages are:

- construction and digging are laborious;
- storage conditions adversely affect viability; the stored grains can only be used for consumption;
- the grain can acquire a fermented smell after long storage;
- removal of the grain is laborious and can be dangerous because of the accumulation of carbon dioxide in the pit, if it is not completely full;
- inspection of the grain is difficult;
- risks of penetration by water are not small, and the grain at the top and in contact with the walls is often mouldy, even if the rest of the stock is healthy.

'IMPROVED' FARM/VILLAGE STORAGE METHODS

Temporary Storage Methods

It is recognized that, although temporary storage methods are the least desirable, there are circumstances in which they are unavoidable. The following suggestions and recommendations for improving such storage methods are offered, on the understanding that more permanent solutions to problems should be sought wherever possible.

Little can be done to improve **aerial** storage except, perhaps, to suggest that the bundles of cereals may be safer if suspended in a well ventilated part of the house; or above a fireplace where insects may be deterred and the moisture content of the grain may be reduced.

As far as **storage on the ground, or on floors** is concerned, the grain is less exposed to risk if it is placed on wattle mats or the like laid on the ground or floor. Drying floors could be improved by making them of concrete; or by stabilising the earth chemically or with natural material such as néré juice. Larger animals are less likely to spoil the grain if such floors are constructed near the house, where they can be better guarded.

If the grain is stored on the floor in a part of the house, it is best to ensure that the floor is clean and stabilised. To prevent the translocation of moisture through the floor to the grain, a plastic sheet should be placed upon it first (or better, embedded in the floor during its construction). The room should be rodent proofed as far as possible (including wire mesh screens fitted to windows), and the grain should be treated with insecticide. Before each new harvest the room should be cleaned, to remove any residual insect infestation.

Open timber platforms may be improved by fitted rodent barriers around the supporting posts. Furthermore, the posts should be driven at least 60 cm into the ground, to withstand pressures caused by wind, uneven loads, or even animals leaning against them (some animals will rub against trees to relieve itches!). To protect them against termites, posts should be coated with bitumen or used engine oil, or superficially charred after having the bark removed. Alternatively, since termites do not attack fresh, healthy wood, green wood which will sprout and grow may be used as poles.

The central post of a **conical-shaped platform** should be at least 80 cm high to prevent rodent attack and, like the poles supporting the upper frame, should be fitted with a rodent barrier. The poles or large bamboos comprising the cone, while being sufficiently strong, must not fit so tight together as to impede the passage of air and retard drying. One solution is to cover the timbers with enough loosely woven wattle (sorghum stems for example), to prevent cobs falling between the timbers, to pass the weight of the grain to the wood and allow air to pass at the same time.

Long-term Storage Methods

The upright poles which support the platforms of **traditional storage baskets (cribs)** should be at least 80 cm high, and protected against termites as described above. They should also be fitted with rodent barriers in similar fashion (Figure 6.7). The poles should be as thick as possible, in order to reduce the number needed and therefore the amount of metal sheet which has to be purchased for making the rodent barriers.

Where it is customary to raise the roof (or part of it) when removing grain from the crib, then the possibility of incorporating a small framed door near the bottom of the wall should be considered. This will prevent damaging the roof and help maintaining its waterproofness. When the platform is conically shaped, an opening in the side of the cone could be practical. If the walls are woven, a trapdoor could be fitted into the platform for access from underneath the crib.

In a dramatic break-away from traditional crib design, while retaining the important principle of using locally available materials as much as possible, the African Rural Storage Centre (ARSC) based at IITA in Ibadan, Nigeria, has developed a crib which optimises both the drying and storage of maize under humid tropical conditions (FAO, 1987) (Figures 6.8 and 6.9).

Such a crib consists basically of two parallel frames between which the grain, mainly cob maize, is stored. The supporting posts are driven 50 to 60 cm into the ground one metre apart and protected from termites with sump oil, tar or scorching. They are then fitted with rodent barriers.

Figure 6.7. Traditional crib fitted with metal rodent barriers.

The walls of the ARSC crib may be constructed of wire netting or local material, such as rafia, bamboo or wooden lattice, and should be 1.5 to 2 metres high. The floor, which should be fixed at least 80 cm above ground level, is made of straight poles; if possible removable to facilitate emptying. The roof may be covered with corrugated metal sheet or thatch, which should overhang a long way to protect the cobs from rain: an overhang of 0.6 to 1 metre is recommended.

The various components of the crib are nailed together, or can be bound together with lianas or bark string.

In very humid areas where maize is harvested at 30-35% moisture content, the recommended width for the crib is 60 cm. In drier zones with a single rainy season, maize is harvested at about 25% moisture content and the width may be increased to 1 metre. In very dry places the crib could be 1.5 metres wide.

The length of the crib is a function of the quantity to be stored. Given that 500 kg of maize cobs with their sheaths removed, and a moisture content of 30%, (equivalent to 300 kg of shelled maize at 14% mc) occupy approximately one cubic metre: if a crib is 60 cm wide and 1.7 metres high, it will need to be 5 metres long to contain the cob equivalent of 1,500 kg of shelled maize at the quoted moisture contents.

If it is possible, the crib should be erected across the direction of the prevailing wind and, if this is strong, the supporting posts should be reinforced to resist it. The crib should be located in a ventilated area and not constructed along a wall or next to a windbreak of trees.

Figure 6.8. ARSC crib constructed with teak poles and corrugated metal roof.

Source: FAO (1987)

Figure 6.9. ARSC crib constructed entirely of locally available materials.

Source: FAO (1987)

Calabashes, gourds, and earthenware pots can be rendered virtually airtight by treating the exterior surfaces with varnish or with dry oil such as linseed oil (McFarlane, 1970). The mouth may be carefully sealed with wax; or covered with a doubled plastic sheet tied firmly in position.

If an absolutely air-tight seal cannot be guaranteed, the grain should be treated with insecticide.

Jars should be treated like small containers (see above) to make them airtight. Very large and immobile jars could be provided with outlets in their bases, for the easy removal of grain. Such outlets could, for example, be metal tubes fitted with lockable caps for greater security. If the cap is well designed it would ensure both security and airtightness.

The following suggestions are made for improving traditional **solid wall bins**:

(a) Where the base consists of a layer of stones, these should be set in concrete or clay mixed with a hardener such as néré juice, to prevent the base becoming a hiding place for rodents (and snakes). An alternative is to make a hollow base with an opening, in which to house chickens (see Figure 6.5.). A solid concrete base could also be made, but the cost is often too high.

(b) When clay is used alone, it is very friable and must therefore be protected. Rendering with pure cement is <u>not</u> recommended, because it resists movements of the walls (expansion, contraction, settling), cracks and becomes detached within a short time. It is preferable to use a mixture of earth and cement (one part cement to ten of earth) or earth mixed with lime (one part lime to five parts of earth) or earth stabilised with a natural product such as guava juice, karité butter, cow dung, opuntia (cactus), flour (in the form of a paste, made by mixing 15 litres of flour with 220 litres of water, which is added to the earth), euphorbia latex, néré juice, etc.

(c) Traditional solid wall bins can be made more secure against thieves by providing each compartment with a lockable outlet at its base. If a mud-plastered ceiling (under the thatch roof) is also provided, with sealable entrance(s) for loading, such an improved bin can be made reasonably airtight.

Underground storage pits may be improved in a number of ways, several of which are already employed locally but are worth adopting elsewhere (Boxall, 1974).

(a) In the first instance, it is very worth while extending the neck, or collar, of the pit above ground level - with clay or even a concrete slab - to minimise the risk of rainwater pentrating at this point. This risk can be further reduced by digging simple drainage trenches around and away from the pit, to remove rainwater from the area as quickly as possible. Such precautions may interfere with the security of the pit, by revealing its presence to potential thieves; so the fitting of a lockable lid should be considered. Alternatively, the pit can be located under a lockable shed, or even under the floor of a room in the house.

(b) The floor of the pit may be strengthened with stones, stabilised earth or even concrete; and the walls may be solidified with cow dung, or chicken wire mesh plastered with cement. A double layer of concrete, each layer about 5 cm thick, with chicken wire (for strength) and bitumen (for waterproofness) sandwiched between, is probably the best type of lining that can be recommended.

(c) Plastic sheeting could be applied to the walls and the floor, but this is not easy and it is probably more practical to put the grain into plastic sacks and stack these in the pit.

ALTERNATIVE STORAGE TECHNOLOGY AT FARM/VILLAGE LEVEL

Sacks

Wherever grain is grown on a commercial basis, buying agencies often issue empty sacks to producers so that they may be filled on the farm. The buying agency may then collect the bagged grain from the farm, or the producer has to deliver it to the nearest collection point. In either case, the producer has to store the sacks of grain for some time before they are sold. During this period precautions have to be taken to ensure the safety of the grain and maintain its quality.

At the very least, the bagged grain must be kept off the ground to prevent spoilage by translocating water and/or termites. Low platforms, tarpaulins or plastic sheeting may serve this purpose; but if there is a risk of damage by rodents or other animals, high platforms fitted with rodent barriers should be used. If there is a risk of rain during the temporary storage period the bags should be covered with waterproof sheeting (but <u>not</u> all the time if the grain has a moisture content much in excess of 12%). Alternatively, the sacks of grain should be stacked on dunnage or waterproof sheeting, away from walls, in a rodent-proofed barn. The need for chemical methods of pest control should not arise if the storage period is short.

Where sacks are used for domestic grain storage, similar conservation measures should be adopted. However, it will be necessary to employ some form of insect pest control (see Chapter 8). Second-hand sacks must be thoroughly cleaned and disinfested before use.

Metal or Plastic Drums

Drums are often used as storage containers in the house and serve notably for the storage of cereal seeds and pulses.

Plastic drums are used intact or after having the upper part cut off to facilitate loading and unloading. Otherwise, plastic lends itself poorly to adaptation because it is relatively weak: at most, a lockable outlet can be added. If the lid is tight fitting and the drum is completely filled with grain, any insects present will deplete the oxygen in the drum and die.

Metal drums can be adapted for domestic grain storage in a similar way. A removable lid permits easy loading; but it is also possible to weld half of the lid to the rim of the drum, and provide a riveted hinge on the remaining half of the lid so that it alone can be opened.

Fitted with a padlock, such a modified drum is more secure. To make a store of greater capacity, two metal drums can be welded together end to end and fitted out as decribed above. Well modified and/or fitted with gaskets, metal drums can also be made airtight.

Inaccessible to rodents, efficient against insects, sealed against entry of water, drums make excellent grain containers. However, they should be protected from direct sunshine and other sources of heat to avoid condensation by being located in shaded and well ventilated places.

Alternative Solid Wall Bins

In some countries grain storage workers, rather than modifying traditional storage structures, have developed significantly different storage bins. A few examples of these are described below.

(i) The "Pusa" bin.

Developed by the Indian Agricultural Research Institute (I.A.R.I.), these silos are made of earth or sun-dried bricks; they are rectangular in shape and have a capacity of 1 to 3 tonnes.

A typical "Pusa" bin has a foundation of bricks, compacted earth, or stabilised earth. A polyethylene sheet is laid on this, followed by a concrete slab floor 10 cm thick. An internal wall of the desired height (usually 1.5 to 2 metres) is constructed of bricks or compacted earth, with a sheet of polyethylene wrapped around it. This sheet is heat-sealed to the basal sheet, and the external wall is then erected. During the construction of the wall an outlet pipe is built into its base.

The concrete slab roof is supported by a wooden frame and, like the floor, is constructed of two layers separated by a polyethylene sheet. During its construction, a man-hole measuring 60 x 60 cm is built into one corner.

The "Pusa" bin (Figure 6.10) has been widely adopted in India, and has been demonstrated in some African countries. It gives good results when loaded with well dried grain.

(ii) The "Burkino" silo

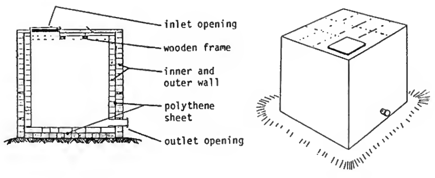
Based on a traditional dome shaped type of bin, this silo is constructed with stabilised earth bricks (Figure 6.11). Various models and capacities are available.

The base is made of stabilised earth resting on the ground or on concrete pillars. The dome-shaped roof is also made of stabilised earth bricks, using special wooden formers. The technique of making a dome-shaped roof is not easy to master, and usually has to be done by skilled masons. A variant has been developed with the roof resting upon a wooden frame, which can be erected by unskilled farmers.

(iii) The "USAID" silo

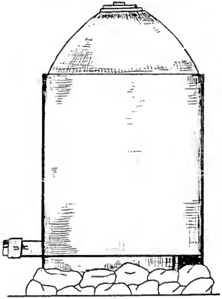
This silo is based on the "Burkino" silo and examples have been erected in Nigeria; holding one tonne of maize grain, the silo rests on stone or concrete pillars supporting a reinforced

Figure 6.10. The "Pusa" bin.



Source: Bodholt and Diop (1987)

Figure 6.11. The "Burkino" bin.



Source: Bodholt and Diop (1987)

concrete slab 1.5 metres in diameter. The walls are made of stabilised earth bricks and are plastered inside and out with cement reinforced with chicken wire mesh. The top is dome-shaped with a central round opening, and covered with a cone-shaped earthen cap. This is plastered with cement, and rests on bamboos or on a metallic drum base. An outlet door, consisting of a 15 x 30 cm plate 1.5 mm thick which is smeared with grease for easy sliding, is let into the base concrete slab.

(iv) Concrete/cement silos

Such silos are 'cement rich', and often include other materials which normally have to be imported into developing countries. Therefore they are potentially (and usually) expensive structures, which can be seriously considered only when improvements to traditional storage bins cannot be practically applied. Their redeeming feature, given that they are properly constructed and used, is that they are robust and should give many years of satisfactory service.

<u>The Ferrocement Bin</u> ("Ferrumbu")

Developed in Cameroon (Østergaard, 1977), and tested in a number of African countries, this bin is similar to the "Burkino" bin in shape but consists mainly of chicken wire plastered inside and out with cement mortar. Details of its construction may be found in Bodholt and Diop (1987).

The wall varies in thickness from 3.5 cm for a bin of 0.9 m^3 capacity, to 6 cm for one of 14.4 m^3 capacity.

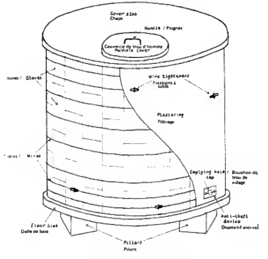
<u>The "Dichter" stave silo</u>

This cylindrical silo (Figure 6.12) was developed in Benin, and is constructed with trapezoidal section concrete blocks (staves) supported externally by tightened steel wire. Both internal and external surfaces are rendered smooth with cement, and the outside may be treated with coaltar to ensure water-proofness. The floor and cover slab consist of reinforced concrete cast *in situ*, and the whole structure is raised off the ground on four concrete block pillars. A manhole is located in one side of the cover slab, and an 'anti-theft' outlet is built into the bottom of the wall. Construction details may be found in Dichter (1978).

Other types of ferrocement or concrete block bins have been designed and tested, notably that developed in Thailand for rice storage (Smith and Boon-Long, 1970) (Figure 6.13). However, as far as is known, none has enjoyed more than local popularity.

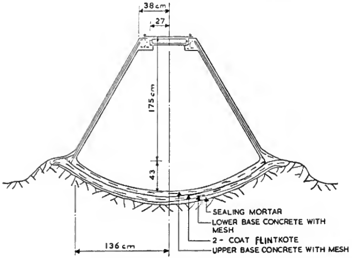
A principal technical difficulty with such bins is that they are poorly insulated, which encourages the development of moulds if the moisture content of the grain is higher than 13%. This means that the bins must be constructed indoors, or at least protected by shelters with a wide overhang to reduce extreme variations in temperature. With tall bins, such as the larger Ferrumbu, this is not very practical.

Figure 6.12. The "Dichter" concrete stave bin.



Source: Dichter (1978)

Figure 6.13. Ferrocement bin for rice, Thailand.



Source: Smith and Boon-Long (1970)

(v) Metal Silos

Economically valid for storing large quantities (over 25 tonnes), metal silos are often regarded as too costly for small scale storage. Nevertheless certain projects have been successful in introducing small metal silos, of 0.4 to 10 tonne capacity, at farm/village level in developing countries: Swaziland (Walker, 1975), Bolivia (Anon, 1982), India (Anon, no date), to mention just a few. Metal silos are reported to have been used on farms and in villages in Guatemala for over 50 years (Breth, 1976) and in Swaziland, on a small scale, for possibly longer.

Such silos are made of smooth or corrugated galvanised metal, and are cylindrical in shape with a flat metal top and, usually but not always, a flat metal bottom. A man-hole with a cover, which may be hinged but is nevertheless lockable, is located, usually to one side, in the top panel; and an outlet pipe provided with a padlock is fitted at the base of the wall.

Metal silos should be placed on platforms or plinths, to facilitate emptying. Large capacity silos are usually constructed without base plates on raised concrete slabs. In this case, bitumen or cement mortar is plastered around the base of the wall to prevent penetration by water and pests.

As with concrete silos, it is essential to provide cover, to avoid excessive variations in temperature and moisture translocation (Figure 6.14).

(vi) Synthetic Silos

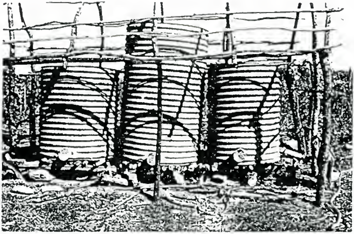
Various attempts have been made to develop small scale storage bins, using synthetic materials such as butyl rubber (O'Dowd, 1971) and high density polyethylene (CFTRI, 1975). However, such bins proved to be either too expensive (Figure 6.15) or prone to damage by pests. Also the management level required by such storage facilities is probably too high for most rural situations.

TRADITIONAL PRIVATE GRAIN TRADER STORAGE

As implied in the Introduction to this chapter, the requirements of private grain traders have tended to be neglected in favour of the development of storage facilities for government or quasi-government grain marketing organizations. Consequently, references to private trader storage facilities are scattered and almost inconsequential. This section is therefore brief and based almost entirely on the author's observations.

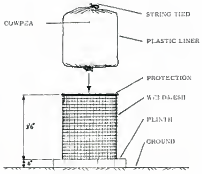
Most private grain traders never have more than a few tonnes of grain in store at any given time; their operating principle being to dispose of stocks as quickly as possible, thereby minimising losses associated with pest infestation and avoiding the extra expense of pest control. With few exceptions, therefore, their storage facilities are small (200 tonnes capacity or less) and absolutely basic in design. Typically consisting of nothing more than a single large room, with bare brick or mud plastered walls, an earth floor, a corrugated metal roof supported by many pillars, and poorly fitting swing doors; a grain store is often one of several traders' stores in a long building sharing a common roof (Figure 6.16).

Figure 6.14. Small metal silos on wooden platform, under frame for shelter, Swaziland.



Source: Tropical Stored Products Information, 32.

Figure 6.15. 500kg butyl rubber/weldmesh silo for cowpea storage, Nigeria.



Source: O'Dowd (1971)

Figure 6.16. Traditional grain trader's store, Zanzibar (Tanzania).

The existence of many roof supports in such a primitive store (Figure 6.17) makes it impossible to build large stacks of bagged grain free of obstructions (a necessary prerequisite for effective fumigation). However the traditional 'banco' store in Mali, with its flat mud roof supported by many pillars, has lent itself well to the 'whole store' fumigation technique using phosphine (Webley and Harris, 1979) (see Chapter 8).

Figure 6.17. Interior of traditional grain trader's store, Guyana.

In production areas of Somalia and Sudan some grain traders are known to hold stocks of grain in large underground pits ('bakar' or 'matmura' respectively). When trading conditions are favourable these stocks are transferred to urban wholesale or retail stores not unlike those briefly described above.

MODERN WAREHOUSES

The Purposes of Warehouses, and Basic Requirements

Warehouses are intended for the storage and physical protection of goods. In the context of grain storage, 'goods' primarily refers to bagged grain. It may also include materials and equipment required for the packaging and handling of bagged grain, and storage pest control; although, in an ideal situation, such items should be stored separately. The distinction is made between warehouses and flat stores, which are designed rather differently for the storage of grain in bulk and are discussed in Chapter 7.

Locating a Warehouse

The approximate location of a proposed warehouse for grain storage will have been decided already. However, the determination of its exact siting is a matter for engineers. If a large warehouse is planned, it is always prudent to involve local Civil Engineers at this stage.

Several factors need to be considered in selecting a suitable site. In the first instance the topography of the area has to be studied. It is preferable to erect the warehouse on level ground, ideally slightly raised above the surrounding area, which is well drained and not prone to flooding. Low locations must be avoided. If it is difficult to find a level area then the least undulating or sloping area should be selected, and the site should be oriented along contour lines, in order to minimise the amount of levelling and filling in to be done.

It is then important to determine the characteristics of the soil: its load-bearing capacity, resistance to compaction, and drainage characteristics. Never build on black cotton soils, because these are weak and do not have sufficient soil-bearing capacity even for small warehouses. The warehouse and the approaches to it will need to be protected from running water by an effective drainage system, and the site should be able to accommodate such a system.

For easy access and movement of stocks, the warehouse should be sited as near as possible to a main road. It is also important to ensure that the approaches to the warehouse will permit easy movement and manoeuvring of vehicles around it. This means that, in addition to the area to be occupied by the warehouse, there should be plenty of usable space around it. Also, looking to the future, there should be sufficient space for the erection of additional warehouses and utility buildings.

In tropical countries it is very important that the long axes of warehouses are oriented East-West as nearly as possible. This way, the side walls are least exposed to the sun and temperature variations inside are minimised. If the warehouse cannot be oriented East-West, some benefit may be derived from siting it across the direction of the prevailing wind. The interior can then be effectively cooled by opening all doors and windows at appropriate times.

Finally, bearing in mind that grain in the warehouse will probably be fumigated with gas lethal to human beings (see Chapter 8) from time to time, it is important that the site chosen must be a safe distance from dwelling houses, shopping centres and other working areas.

Standard Warehouse Design (for information on fumigable warehouses, see Annex 4)

All warehouses consist of a floor, walls, a roof, and one or more entrances. However, they can vary considerably in the detailed composition and construction of these basic components; and may include others, such as ventilators, windows, artificial lighting, etc. The various combinations of features possible have to be considered very carefully, together with other factors relating to location, intended use, etc., when planning the construction of a warehouse.

Paramount importance should be attached to ensuring that the quality of the commodity to be stored will not be affected by physical factors such as moisture and heat. Wherever possible and practical, the design of the warehouse should incorporate features which will protect its contents from attack by rodents and birds, and facilitate the use of insecticides.

The warehouse should also be easy to clean and maintain (there is no point in using components which are not readily replaceable or repairable); and it should provide good working conditions.

(i) Foundations and Floor

Unstable clay soils and areas which have been filled in should be avoided wherever possible, because they involve the risk of subsidence. In all cases, it is necessary to dig down to a point where the soil-bearing pressure is $150kN/m^2$ or better.

The floor must be able to bear the weight of the grain which will be stacked upon it, and it must also be impermeable to ground water. For these reasons the floor should consist of a slab of reinforced concrete laid upon well compacted hard core, with a moisture barrier sandwiched between the two. This moisture barrier should consist of a layer of bitumen or asphalt, bitumen felt, or a polyethylene film.

The reinforced concrete slab must be made with expansion joints, to prevent cracking (which makes storage hygiene difficult). It should be covered with a cement cap a few centimetres thick, which is rendered smooth and hardened (to prevent powdering). Ideally, the concrete slab should be laid after the roof has been completed: to prevent direct sunshine drying it too rapidly, and possibly causing it to crack.

The floor level must be sufficiently above ground level to ensure that water will not enter the warehouse, even after the heaviest rainfall that can be expected. Consideration could be given to erecting the warehouse on a plinth raised about 1.2 metres above ground level, to facilitate loading and unloading of vehicles; but this alternative is expensive and can add 40% to the cost of construction.

(ii) Walls

Most modern warehouses are constructed with a framework, usually of reinforced concrete. The supporting pillars are linked together by lower tie-bars, which are themselves secured to the floor slab, and by upper tie-bars, which hold the frame firmly together. It is essential that all joins are secure and accurate, and that the reinforcing rods are well covered with

concrete. The walls of the warehouse are built between the supporting pillars.

If the supporting posts are thicker than the walls, it is important that the extra thickness is on the outside of the building so that the internal surfaces of the walls are smooth and free from projections. This facilitates cleaning of the store, and avoids interference with other operations as well.

The walls may be made of breezeblocks, or stabilised earth bricks 15 to 20 cm thick, and should be rendered smooth on both sides. They should be painted white, on the inside to facilitate the detection of insect pests, and on the outside to help keep the warehouse as cool as possible. Alternatively, the walls may be made of a lightweight material such as fibro-cement, galvanised metal sheet, or aluminium sheeting. However, walls of this kind are easily damaged, have poor insulating properties, and are sometimes prone to erosion.

A vapour-proof barrier should be incorporated into the base of the walls, to prevent damp rising and causing damage to the warehouse structure and its contents. Also, a concrete strip about 1 metre wide should be laid around the outside of the warehouse, to prevent rain from eroding the base of the walls below the damp course.

(iii) Roof

Internal pillars supporting roof frames should be avoided because, as previously stated, they can interfere with pest control and other stock management procedures. Instead, roof frames should be designed so that they transfer the weight of the roof to the supporting columns (in framed buildings), or to the walls if the warehouse is small.

Modern engineering techniques allow very wide 'free-span' roofs (i.e. roofs without internal supporting pillars) to be constructed. However, such roofs are very expensive and rarely used in warehouse construction. A steel portal frame should be used if the span is to be greater than 15 metres. Warehouses less than this width may have reinforced concrete roof frames.

Roof frames made of wood or bamboo are only suitable for warehouses not more than 4 or 5 metres wide. The wood used must be well dried and treated with a preservative.

Roof cladding may be of galvanised steel or aluminium sheeting, or asbestos cement; the latter being more fragile but having better insulating properties. Tiles are not recommended, especially for large warehouses.

The roof should overhang the gables by 0.7 to 1.0 metres, and the eaves by at least 1 metre. This ensures that rainwater is shed well clear of the walls; and obviates the need for guttering and drainpipes, which may become blocked or assist rodents entering the warehouse. The overhang also helps to keep walls cool and protects ventilation openings from rain.

(iv) Ventilation

Ventilation openings are necessary for allowing the renewal of air and reducing the temperature in the warehouse, they also allow some light to enter it. If such openings are

located too low down they can be the source of numerous problems: entry of water, rodents, thieves, etc. These problems are avoided when ventilators are placed under the eaves. They should be fitted on the outside with anti-bird grills (20 mm mesh) and on the inside (10 cm behind the grills) with 1 mm mesh screens (removable for cleaning) which will deter most insects.

(v) Doors

The number of doors will vary according to the size of the warehouse. If possible there should be at least two doors, so as to be able to rotate stocks on a 'first in, first out' basis. Hoever, this may not be possible or practical in a very small warehouse.

Double sliding doors are recommended. Preferably made of steel, or at least reinforced along their lower edges with metal plate as protection against rodents, they should be sufficiently large (at least 2.5 x 2.5 m) and close fitting. If swing doors are fitted they should open outwards in order not to reduce the storage capacity of the warehouse. It is recommended that the doors be protected from rain by an extension of the roof or a separate cover.

(vi) Illumination

Adequate light in a warehouse is an important factor as far as the safety of workers inside it is concerned. However, there can be problems in providing sufficient natural light while satisfying other technical aspects at the same time.

Many warehouses are fitted with translucent sheets in the roof. However this is considered inadvisable, because it may involve the risk of spot heating of produce in the top layers of stacks underneath. Other warehouses are reasonably well lit by daylight filtering through ventilation gaps left along the tops of side walls. This source of illumination is impaired by the installation of bird-proofing. Non-opening windows set high up in walls may solve this problem; although their sills could harbour pest-infested grain residues, unless they are specially sloped to prevent this happening.

Most warehouse managers find that leaving several doors wide open during the hours of intense sunlight in tropical countries provides adequate illumination of the interior. This is probably the most practical solution when all open doorways are in active use. Otherwise, it does invite the risk of theft, or furtive access by rodents.

Artificial lighting is justified only in warehouses which are regularly worked in during hours of darkness.

Determining the Dimensions of a Warehouse

Before calculating the dimensions of a warehouse it is important to identify the function it is intended to perform. If it intended to be a *transit* store, and bagged grain will be moved through it quickly, stacks are likely to be low and plenty of working space will be needed. If, on the other hand, it is to be used for the *storage of reserve stocks*, stacks will need to be as high as possible and only minimum working space will be required.

Figure 6.18. Standard warehouse with a working area at one end.

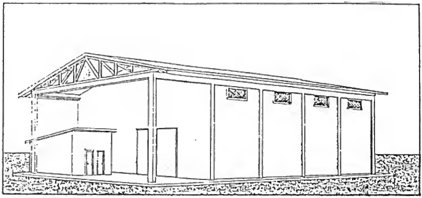
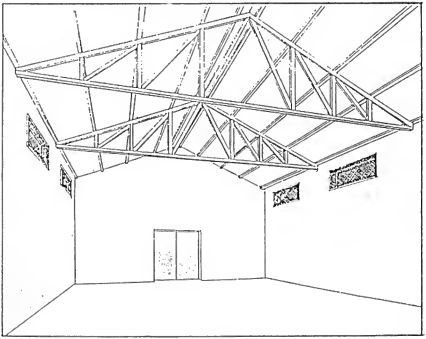


Figure 6.19. Inside view of a standard warehouse.



Source: Cruz and Diop (1989)

The dimensions of a warehouse are calculated mainly from:

- (i) the *Specific Volume* of the principal product to be stored;
- (ii) the *Maximum Tonnage* of this product which it is desired to store;
- (iii) the *Maximum Stack Height* desired;
- (iv) the extent to which *Separation of Lots* is desired.

An example of how the dimensions are calculated, using these parameters, is given on page 162.

(i) The Specific Volume of the Product

This is defined as the volume occupied by 1 tonne of the bagged grain. The term Specific Volume may be similarly defined for grain stored in bulk, which is the subject of the next chapter.

Engineers find it more convenient to use Specific Volume rather than Bulk Density (see Chapter 3) in their calculations. However, even now, there is a tendency to use bulk density data in determining specific volumes for products. This tendency is queried (Clancy (1977) and Hayward (1981a)) because large quantities of bagged grain in stacks or bulk grain in silos become compacted, and occupy less space than bulk density calculations indicate. Clancy found that bulk wheat can pack by 1% or more, while Hayward discovered that the average density of bagged millet exceeded quoted bulk density figures by up to 40%.

While Specific Volume is regarded as a valid parameter, it is recommended that engineers responsible for designing warehouses should collect as much information as possible on the specific volumes of locally important products to guide their calculations[2]. For what it is worth, Table 6.1. gives the specific volumes of a number of products for which warehouse accommodation is frequently required.

Table 6.1. Specific volumes of some bagged grains and grain products.

Commodity	Specific Volume (m^3/t)
Bulrush millet	1.25
Beans, peas, lentils	1.30
Wheat, milled rice, coffee	1.60
Maize, sorghum, decorticated groundnuts, palm seed	1.80
Soybeans, cocoa	2.00
Wheat flour, maize meal	2.10
Cotton seed	2.50

[2] Hayward carefully recorded the dimensions of well constructed stacks of bagged millet, the total weights of which were known, together with average percentage moisture contents of the grain in each. He then used averaged data to make his comparisons. This procedure can easily be followed elsewhere, and the information gathered could be usefully publicized for the benefit of other warehouse construction engineers.

(ii) Maximum Tonnage

This parameter will depend upon the purpose for which the warehouse is required. The quantity calculated should also take long-term projected requirements into account.

(iii) Stack height

This also depends, in part, upon the purpose for which the warehouse is required (see above). The nature of the commodity and the type of sack to be used are additional factors to be considered.

Some commodities, notably palm seed and cocoa, cannot be stacked very high because they compact easily. Sacks made of woven polypropylene have a tendency to slide on each other, and therefore should not be stacked more than 3 metres high. Jute sacks bind together better, and may be stacked up to 6 metres above the floor.

The height of stacks should not exceed the height of the walls, and a space of at least 1 metre should be allowed between the tops of stacks and roof frames.

(iv) Separation of lots

Maximum use of the warehouse is gained by storing products in one stack. However, it is usually necessary to separate lots; and, for better stock control, gangways have to be provided between and around stacks. Spaces 1 metre wide should be left between stacks and between stacks and the walls. Also, it is customary to provide one or more areas at least 2 metres wide, in which incoming or outgoing stocks can be handled.

Ancillary Buildings and Structures

Warehouses are often constructed without consideration being given to how the storekeeper, equipment and consumable items (empty sacks, pesticides, etc.) are to be accommodated. The storekeeper is then obliged to section off parts of the warehouse as his 'office' and storage areas for equipment and other items. Apart from thus wasting valuable space, this practice is also hazardous when stocks of grain have to be fumigated. It is always better, therefore, to include an office and other ancillary buildings, adjacent to the warehouse but a safe distance from it, right from the early planning stages.

The provision of toilets and washing facilities for workers is a statutory requirement in many countries, but often overlooked. Larger grain storage installations may also require quality control laboratories, workshops and garages for vehicles, and so on. An incinerator for the destruction of spoiled grain and combustible waste material would complement other pest control measures, and reduce rubbish disposal costs.

In order to make maximum use of the storage space <u>inside</u> a warehouse, it is often advantageous to extend the roof at one end (Figure 6.18), or along one side, to provide a covered working area for the handling of stocks being received or despatched.

For further detailed information see FAO (1985),

Example of how the dimensions of a warehouse are calculated

In this example it is assumed that a warehouse is required for the storage of 1000 tonnes of maize in jute sacks in 4 separate lots. It is also assumed that the warehouse will be rectangular in plan, with the length approximately twice the width.

From the specific volume of maize (Table 6.1), the total volume of the stock will be:

$$1000\ (t) \times 1.8\ (m^3/t) = 1800\ m^3$$

If the sacks of maize are to be stacked 5 metres high, the floor area required will be:

$$\frac{1800}{5} = 360\ m^2$$

If length (L) = 2 x width (W), then:

$$2W^2 = 360\ m^2, \text{ or } W = 13.4 \text{ metres}$$

Keeping the example simple, let W = 12 m; then, the area being 360 m^2, L = 30 m.

If the stock is to be kept in four separate lots, each measuring 6 x 15 metres, then the following floor space will also be required:

a main handling area, 3 metres wide, along the axis of the warehouse;
a gangway 2 metres wide, across the centre of the warehouse; and
an inspection space 1 metre wide around the entire stacking area.

The internal dimensions of the warehouse will be:

- Width (W) = 1 m + 6 m + 3 m + 6 m + 1 m = 17 metres
- Length (L) = 1 m + 15 m + 2 m + 15 m + 1 m = 34 metres

giving a total floor area of 578 m^2.

If the warehouse is to have a trussed roof, the walls should be at least one metre higher than the intended stacking height: in this example 5 m + 1 m = 6 metres.

The percentage utilisation of the building will then be: $\frac{1800 \times 100}{578 \times 6} = 52\%$

NOTES:

Similar calculations indicate that in small capacity warehouses (10 to 30 tonnes) only about 20% of the space is usable. Medium capacity warehouses (50 to 100 tonnes) have only about 30% usable space. Thus the larger a warehouse is, the more economical it will be in terms of cost of construction per tonne stored.

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CHAPTER 7

BULK STORAGE

INTRODUCTION

As has been discussed at length in Chapter 1, there are many reasons for storing food grains and also numerous types of storage facility available. For any given situation there is usually a choice of storage methods. Chapter 6 has described traditional types of storage used in developing countries, and also warehouses for the storage of bagged grain. This chapter concentrates on structures available for the storage of grain in bulk, where this is deemed most appropriate and economical in commercial grain handling systems.

Centralised bulk storage facilities which receive grain from farmers and safely store it for maybe 12 months or until it can be exported or disposed of domestically, provide a combination of strategic, commercial and buffer storages. Their essential purpose is nevertheless that of long-term operational storage in that they provide a buffer between harvest receivals and the markets or consumers of grain.

The type of store most suitable for a particular situation often depends on the purpose for which it is to be built.

FACTORS INFLUENCING THE CHOICE OF BULK STORE

Compared to most other foodstuffs, such as meats and vegetables, grains are relatively easy to store. If grain is kept insect-free and below its safe moisture content, it will keep for many years with minimal loss of quality or nutritional value. Low temperature is an important factor in minimising insect activity and in maintenance of nutritional quality in general. Storage at or below the safe moisture content is essential for prevention of deterioration caused by microorganisms and insects (see Chapters 2 and 8 respectively).

Where insects are present, temperatures are high, and most especially where moisture content is above safe levels, then storage of grain becomes both risky and difficult, and losses will be difficult to avoid. It is in these circumstances that the type of store and its design become critical to the safety of the stored grain. It is worth remembering that most often, the value of the grain (in dollars-per-tonne) is usually greater than the cost of the structure in which it is stored. Minor expenditure in improving the quality of the store can thus be quickly recovered if commodity losses are commensurably reduced.

Whilst the choice of storage design is wide, the essential requirements needed to store grain safely remain the same. These are that the storage structure must keep the grain free from water ingress, insects, rodents and birds. The store should also permit easy and economical disinfestation of grain in the event of insect infestation and, if grain is to be stored at moisture content above 'safe' levels, provision should be made for cooling the grain. These matters are discussed in more detail in the following sections.

Size of Grain Storage

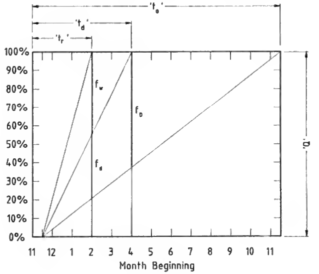
Mathematical, graphical or computer modelling can be helpful in determining the volume of storage that is required. In some cases, it is a relatively simple exercise to determine the requirements - for instance where harvested grain is to be received over a short period, dried over a longer period and dispatched over 12 months, it is a simple matter to calculate the buffer storage requirements for wet and dry grain. This type of situation can be illustrated by a simple graphical model as shown in Figure 7.1. Here, a quantity "Q" tonnes of grain is assumed to be received into storage over a period "t_r" days, and dried over a period "t_d" days. It is then dispatched over period "t_o". If we assume a uniform rate of drying and dispatch, then the maximum wet storage requirement is:

f_w*Q where f_w (the wet storage factor) = $(1 - t_r/t_d)$;

and the maximum dry storage requirement is:

f_d*Q where f_d (the dry storage factor) = $(1 - t_d/t_o)$.

Figure 7.1. Model for determining the Volume of storage required.



Note: See text above for explanation of symbols used.

More complex models are required where the rates of receival and out-turn are less clearly defined; for instance at a shipping import terminal where the rate of receival will depend on ship arrival rates, berth availability etc, and where out-turn rates may depend on the inland

transport system. In such situations computer models are very helpful in optimising various design parameters including the storage volume, number of berths, ship unloader capacity and out-turn capacity. An optimum-cost solution can thus be determined through sensitivity analysis, by varying the values of the input parameters.

Specialised software is available for such modelling exercises, however in simpler cases models can be developed on spreadsheets to produce satisfactory results.

Specialised programming languages are available which are especially useful in simulation modelling 'systems', for instance, where it is desired to look at complete storage and handling systems in a region. Such languages are available for PC applications include SLAM II (produced by Pritsker Corporation of the USA), SIMAN (produced by Systems Modelling Corporation of the USA) and GPSS/H (produced by Wolverine Software Corporation). These modelling languages are not inexpensive, and require training to use them effectively.

Selection of Storage Type

Once a storage need is identified, the choice arises as to the type of store that is most suitable for a particular application. The following storage options may need to be considered: round or rectangular, tall or short, steel or concrete, flat floored or hoppered, permanent or temporary.

Some basic guide-lines, or principles, are offered:

(i) Round or Rectangular

In terms of structural cost per tonne of storage, round stores are generally more economical than rectangular ones. The reasons are simple:

Firstly: grain exerts a horizontal pressure on the structure which contains it. A round store will resist this pressure through the development of hoop tension forces which are very efficiently resisted (eg by steel reinforcement). A rectangular structure must resist grain loads through the development of bending stresses which are less efficiently resisted than tensile loads since both tensile and compressive forces have to be resisted. In addition, in the case of a rectangular 'horizontal' store, the walls act as retaining walls and their foundations have to resist overturning moments caused by the grain loads. Foundations for cylindrical structures have mostly to resist the vertical loads imposed on them from the walls.

Secondly: the roof structure of a rectangular structure has to carry its loads in bending, compared to the roof of a cylindrical structure which can be designed as a shell (for instance a cone), which carries its loads in direct compression and tension.

Another important advantage of cylindrical structures is that they have less joints. In the case of silos where the bins are independent (i.e. not connected to each another), there is a joint between the wall and the floor, and a joint between the wall and the roof. It is thus usually a relatively simple matter to seal these joints to make the structure air-tight and suitable for fumigation. Ideally the roof should be rigidly attached to the wall, since this not

only makes sealing easier, but also greatly increases the stiffness of the wall in resisting bending stresses. In such cases silicone type sealants are useful for sealing the roof-wall joint, however where a sliding joint is required bituminous based mastic sealants sandwiched between the joining surfaces have been successfully used.

Rectangular structures, by comparison, have more joints (for instance at the corners) and by the nature of their construction, sealing for fumigation is generally more difficult to achieve.

Horizontal stores have another inherent disadvantage, in that they require more complicated and longer conveying systems to place grain in them. Usually an internal conveyor is required with a tripper (or similar device) to spread the grain over the floor surface. A cylindrical store, on the other hand, requires only a central point for filling.

(ii) Tall or Short

In the case of flat bottom stores, structural efficiency is also increased by minimising the height of the structure. For a given volume of storage, the lower the height of the walls, the more grain pressure is applied directly to the floor surface and the less load there is on the walls. Furthermore, the minimum structural surface area (and hence cost) for a given volume of grain, is achieved if the wall height is relatively low. For instance in the case of a cylindrical 'tank' with a conical roof, the minimum surface area of walls and roof is achieved when the wall height is around half the radius of the bin. It is thus no coincidence that the lowest cost stores are generally in the shape of squat cylindrical 'tanks' where the walls are relatively low compared to the diameter.

To take an example: a rectangular warehouse or shed structure may typically have a wall height of say 8 metres, and a length about 2½ times the width. Thus to store 12,000 tonnes of corn (or say 16000 cubic metres) with a repose angle of 30°, it may be calculated that the length of the shed will be about 60 metres and the width 24 metres. By comparison, a tank store with the same volume and same wall height will have a diameter of about 41 metres. A comparison of the structural surface areas of the two alternatives gives the following results:

Table 7.1. Comparison of structural areas for 12,000 tonne stores.

Comparison of Structural Areas for 12,000 tonne Stores		
Area	Warehouse	Tank
Wall Surface	1510 m^{2*}	1000 m^2
Roof Surface	1660 m^2	1524 m^2
Floor Surface	1440 m^2	1320 m^2
Total Area:	4610 m^2	3844 m^2

* Including 'gable' end walls.

Figure 7.2. 60,000 tonne horizontal bulk grain storage shed. Note heavy buttressing of walls. Also, the central filling point requires an internal conveyor to spread the grain along the length of the shed.

Figure 7.3. Two 48 metre diameter 20,000 tonne tank stores. Note the absence of wall buttressing. The central filling points require no internal conveyors to spread the grain.

Since the structural components are represented by the surface areas, then the comparison can be used as a preliminary gauge of relative cost. Additionally as mentioned earlier, the walls and roof of the tank store will usually be lighter and less costly than those of the warehouse.

Tank storage is not, however, suited to all situations; for instance where high throughputs are required it is usually desirable to have a self-emptying bin using a sloping floor. In such cases, it is more economical to design higher walls of smaller diameter: to minimise the cost of hopper bottoms (which are usually suspended above ground level) and the risks of ground water infiltration, and to facilitate conveyor design and installation. In instances where land values are high, or where space is limited, it may be expedient to opt for tall bins, even with flat floors to maximise space utilisation.

The chief disadvantage of flat bottomed stores is associated with the difficulty of emptying them and in removing the 'dead' grain that is not discharged by gravity. There are various means of achieving this; for instance portable conveying equipment may be used, or pneumatic systems, or front-end loaders. Another commonly used alternative is the sweep conveyor (usually a screw or auger) which automatically rotates about the bin centre and draws the grain towards the discharge point. Sweep conveyors are usually buried under the grain when the bin is full, and operate only after gravity discharge is completed. Sometimes they are suspended above the grain surface and lowered with winches to perform their function. Either way, it should be born in mind that the investment in permanently installed sweep conveyors can be high, and is seldom warranted if they are to be operated only once or twice per year.

Nevertheless, where low throughputs are required, such as when a store is to be filled and emptied only two or three times a year, the lower capital investment in a large diameter flat store outweighs the additional capital and operational costs associated with emptying it. An analysis of capital and operational costs is usually necessary to evaluate minimum cost solutions where a store may be emptied more than (say) five times per year.

(iii) Construction Materials

The choice of construction material is usually between steel and concrete, though in some countries timber or masonry are still used as alternatives.

The choice between steel and concrete is dependent on a number of considerations, all of which ultimately come down to capital and operational costs. The fact that in most countries steel and concrete are both so widely used indicates that these costs are generally not dissimilar.

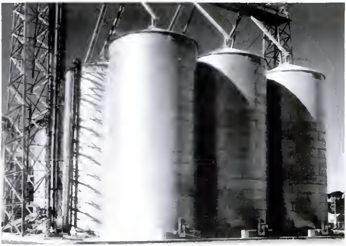
Where price considerations do not dictate the type of construction, the following observations may be helpful:

* Steel silos are often quicker to erect than concrete ones (though this is not universally true).

* Steel silos provide excellent storage where grain is dry. Where grain moisture content is high, there may be a greater likelihood of moisture migration developing due to the heat conductivity of the steel causing temperature gradients to develop between the inside and outside of the grain mass. This in turn can result in moisture condensation on the surface of the grain.

* Welded steel silos will remain gas-tight throughout their lives since they are not subject to cracking or differential movements. They are however subject to corrosion and require maintenance to keep the paint coatings effective. Choice of coating system is an important consideration, as it will effect both capital and maintenance costs; paint systems should be selected to suit particular requirements and expert advice should be sought, particularly in potentially corrosive environments.

Figure 7.4. Bolted Steel Silo.



* Proprietary bins made from light gauge bolted steel panels are a low cost storage option (Figure 7.4). They can be difficult to seal adequately for fumigation due to the large number of bolts requiring sealing (8,000 to 10,000 in a 1000 tonne silo). With light gauge steel panels there is a likelihood of distortion of the bolt holes and relative movement between panels when the silo is under load. Choice of sealing washers under bolt heads and nuts is important, and impregnated felt washers are reputed to perform much better than unreinforced neoprene types which tend to distort under pressure. Silicone type sealants are effective as a sandwich seal between panels, and specially formulated high build acrylic brush applied sealant is useful for sealing joints between roof and wall, and between floor and wall. The acrylic is usually reinforced with fibreglass or similar fabric.

Some suppliers give warranties that their bins can achieve and retain their air-tightness. Where this is proven to be the case, this type of bin can be quite satisfactory for long-term storage. The extra cost of sealing such bins is in the order of US$ 5.00 per tonne.

* Another type of proprietary steel bin is the Lipp silo (Figure 7.5), formed from spirally wound galvanised steel strip or coil. The process involves continuous rolling of the coil to form the cylindrical silo wall, including folding of the adjoining edges to connect and seal them. Only thin steel (up to 4mm) can be used for the process, hence vertical stiffening of the walls is necessary for larger silos, above about 1200 tonnes.

Figure 7.5. Lipp silos formed from continuous steel strip.

Bins any larger than this (1,350 tonnes, 12 metre diameter) require internal vertical stiffening to prevent buckling of the thin steel wall. They are painted white to reflect solar radiation, thus minimising surface temperatures.

Once the foundations are built, the roof prepared and the rolling system is in place, erection of Lipp silos is relatively rapid, taking a few days per bin (similar to slip-formed concrete silos). It does however require skilled operators to keep the walls cylindrical and vertical. Another consideration is the need to use specially formulated steel strip which is manufactured in only a few industrialised countries.

* Steel bins are less robust than concrete bins and require careful engineering design. For instance there have been many instances of steel bin failures resulting from unforeseen grain loads, particularly during emptying; eccentric loadings resulting

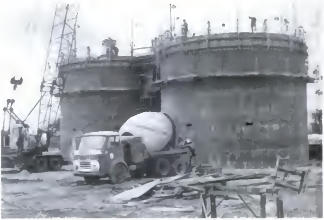
from discharging the grain from the side rather than the centre of the bin should always be avoided in steel bins. Complex engineering solutions are needed to evaluate the buckling strength of the bin walls and also the complex stress combinations in hopper bottom steel silos at the joint between wall and hopper.

* Generally, where very tall bins are required (above about 25 metres high), steel becomes uneconomical because of the extra steel - often in the form of vertical stiffeners - that is required to resist compression buckling of the walls. By comparison, concrete bins only require enough steel to resist hoop tension forces, the vertical compression loads being carried by the concrete.

* Concrete is usually the preferred construction material in coastal areas or where high corrosion risk is severe (see above). As also mentioned above, it is also usually preferred where bins have to be very tall (above 30 metres).

* Tall concrete bins are usually constructed using slip-formed techniques. This involves the use of specialised equipment for moving the forms, however the technology is well known and used throughout the world. Because it involves the continuous pouring of concrete over several days, high levels of supervision are required to ensure satisfactory results. There have been many instances of poor construction quality and even silo failures as a result of inadequate supervision of the work as it is done.

Figure 7.6. Slip-formed silo under construction. The moving forms supported by 'yoke' frames and hydraulic jacks can be seen at the top of the picture. The suspended platform below is to provide access for finishing of the concrete.



* Another common method of concrete silo construction uses 'jump' forms, where the walls are constructed in individual lifts with joints every 1.2 metres or so. Good formwork and an experienced contractor are required to achieve good results.

Construction is slower than with slip-formwork, but labour requirements are lower also, and set-up time is usually less. Because it is a non-continuous process, supervision is somewhat easier. Careful treatment of the horizontal construction joints between each lift is necessary to ensure water tightness and gas-tightness.

Figure 7.7. Jump-form construction. A very small labour force is required for this type of construction compared to slip-form construction, and all lifting is done using deck mounted hoists. The picture shows formwork being 'jumped' - or lifted - from the cast concrete below, in preparation for the next pour.

Short walled 'squat' concrete silos are more commonly constructed using either fixed form (in-situ) construction, or 'tilt-up' methods (Figure 7.8). This latter system involves casting of wall panels on the ground, and lifting them vertically into position. Post-tensioned cables are used to hold the panels together and to resist the grain loads imposed on them.

* With tall concrete silos, it is traditional in many countries to build bins that interconnect with one another, forming 'star-bins' between the main bins and thus providing additional storage. However there are several disadvantages in this form of construction which should be considered. Firstly, their construction is more difficult than that of individual unconnected bins and costs are therefore higher; also the interconnections create bending stresses in the bin walls which may cause cracking to occur. This can lead to difficulties in achieving gas-tightness for fumigation. Often it is no less costly (in unit cost per tonne of storage) to build separate dis-connected bins, and in most cases this should be the preferred option (Figure 7.9).

Figure 7.8. Precast 'tilt-up' concrete panels forming the walls of the 'tank' silos shown in Figure 7.3.

Figure 7.9. Independent concrete bins, Pinkenba export terminal, Australia. These bins have remained gas-tight since they were constructed in 1968, despite heavy usage (a turn-over of up to 30 times per year).

Roof construction is also simpler with independent bins, and gas-tightness of the wall-to-roof joint is usually easier to achieve. Independent bins do, however, use up marginally more land area (because of the space required between the bins) and conveying distances are also slightly increased.

Independent (disconnected) bins also permit the use of conical roofs which are structurally more efficient and lighter than flat slab roofs. Cast-in-situ concrete conical roofs are expensive to form, however costs can be saved using steel, either welded on the ground and lifted into place, or using a light structural frame and placing individual roof sheets into position. An alternative is to precast concrete panels and to place them into position one by one to form the cone.

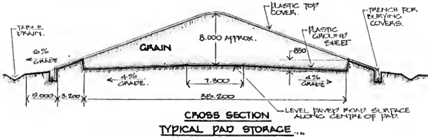
Figure 7.10. Conical precast concrete panel silo roof. The pre-tensioned roof panels were transported to site, lifted into position and anchored to the top of the silo wall. All joints were sealed to render the silo gas-tight for fumigation.

* Contrary to general belief at one time, it is not difficult to achieve and maintain high levels of air-tightness for fumigation in concrete silos without recourse to sealing membranes, post-tensioning or other measures. It is however easier to achieve and maintain gas-tightness in independent bins than in interconnected ones. Care in design is needed to minimise risk of wall cracking (by limiting tensile stress in reinforcing steel) - i.e. by providing adequate reinforcement to the walls, preferably in a double rather than a single layer. Good construction supervision is also necessary throughout the construction period to ensure conformity with design and specification requirements.

* Concrete silos are not well suited where CO_2 may be used for disinfestation of grain. CO_2 reacts aggressively with calcium hydroxide in the cement matrix of hardened concrete, forming calcium carbonate and water. The process is called carbonation, and it occurs naturally (but very slowly) with CO_2 in the atmosphere, and slightly faster with the CO_2 that is generated by respiration of the grain inside the silo. When high concentrations of CO_2 are used in concrete silos for disinfestation purposes, large amounts of gas are 'absorbed' by the concrete giving rise to loss of concentration, and also the risk of high negative pressures developing in the bin if it is well sealed. Carbonation is not detrimental to the concrete, but it chemically neutralises the alkalinity of the calcium hydroxide which provides corrosion protection to the reinforcing steel. The use of fly-ash as a cement replacement is not recommended as it is reported to increase the rate at which concrete carbonates.

* Another type of storage is the "dome" or hemi-spherical shaped concrete silo, constructed using pneumatic inflation either before or after placement of the concrete. Some structural problems have arisen with domes constructed by inflation of the concrete when it is still wet (i.e. where the concrete is placed prior to inflation) due, it is believed, to difficulties involved in achieving concrete compaction and in maintaining a truly spherical shape to the shell. Domes constructed by "shot-crete" application of concrete after inflation of an outer sealing membrane are reported to be more robust. Typically, unit capacities are around 2500 to 5000 tonnes.

Figure 7.11. Cross section of an earth-wall bunker store as used in Queensland, Australia. Precast concrete panels are an alternative form of wall construction which is commonly used.



* The lowest-cost form of storage is the 'bunker' store (Figure 7.11) where grain is placed on a prepared (and well drained) surface, and covered with a plastic sheet. This technique was first developed in Australia, where it is extensively used to supplement permanent storage capacity. Several million tonnes of grain are stored each year in bunkers. Capital costs are very low, however operational costs are higher because of the manpower involved in filling, covering and emptying them. Storage volumes of 25000 to 50,000 tonnes in one bunker are not uncommon.

Despite the apparent risk to which the grain is put in bunker storages, losses are generally very low provided the storages are well drained, and regularly monitored to check for damage to the plastic covers. In Australia, losses are generally much less than 0.1%. Bunker storages are ideally suited for fumigation with phosphine provided care is taken in sealing of joints in the covers. The system has been adopted by many countries outside Australia.

SEALED STORES

When a new grain store is being planned, there should be no question as to whether or not it should be possible to seal it effectively to make it air-tight for fumigation. The benefits of sealed stores are such that the small costs involved during initial construction (negligible in many cases) should not warrant consideration. Despite claims to the contrary, there are no disadvantages to building sealable stores, and when circumstances arise where ventilation is required (e.g. to aerate the grain), ventilators can be provided to allow this to be done.

Low-cost sealing is most easily achieved at the design stage. Retro-sealing of stores which have not been designed to be sealed can be expensive, and in some cases (particularly with small stores) it can be uneconomical. Sealing technology has been developed extensively in Australia where the warm climatic conditions are highly conducive to insect pests and where the need arose to develop means of effectively and economically controlling them. In Queensland, Australia, all stores constructed since 1975 have been built to strict gas-tightness standards, and for many years all new stores have been built to such standards throughout the country. In Western Australia, some 60% of stores are sealed, most of which have been retro-sealed in the last 15 years.

Fumigation of grain is much cheaper and more effective than the use of chemical protectants, and residue problems are avoided. Furthermore, once fumigated, grain in a sealed store can be maintained free from insects because the sealing prevents access for reinfestation. 100% mortality can only be achieved if grain is fumigated in properly sealed stores, which are routinely tested to check their gas-tightness (see below).

Diurnal temperature variations cause pressure changes in the air inside the store, and it is usually uneconomical to design stores (in particular their roofs) to withstand the pressure differentials that can occur. Some means of ventilating sealed stores is thus necessary to avoid these pressure exceeding safe values. Pressure-relief valves should be pressure actuated; in other words they should remain sealed when pressures are below the critical value. One option is to use an oil bath with a baffle extending below the liquid surface such that air-pressure inside the store will displace the oil and allow air to pass below the baffle. Non-evaporative oil should used for the purpose.

Another type of valve uses counter-weighted diaphragms which lift off gasket seals when the pressure reaches a preset value such as are used in the oil industry for protecting oil tanks from damage as a result of internal pressure changes. See Figure 7.12 (opposite).

Steel bins are particularly prone to diurnal pressure variations due to the thermal conductivity of the steel. Internal air temperature changes can be minimised by painting the steel surfaces white since this will significantly reduce day-time steel temperatures by reflecting much of the sun's radiation. It should be noted that galvanised surfaces do not reflect as much radiation as white surfaces, and these should be painted white also.

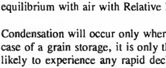
Condensation, Moisture Migration and Moisture Diffusion

The question of condensation risk often arises in any discussion about sealed stores, especially in the case of steel structures. Yet there is little evidence to support the theory that sealed stores actually cause condensation. Theoretically, there should be less risk of condensation in sealed stores than in unsealed ones provided the grain stored in them is at or below its 'safe' storage moisture content.

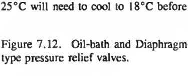
In a properly sealed store at constant temperature, the grain and air mixture are in moisture-equilibrium with each other. Different grains have different moisture equilibria with air, and for each grain type, the moisture equilibrium level changes slightly with temperature. Typically, however, grain at a 'safe' moisture level of 12 to 13% is in equilibrium with air with Relative Humidity of about 65%.

Condensation will occur only where the air temperature drops below its Dew Point. In the case of a grain storage, it is only the air in the 'head-space' above the grain surface that is likely to experience any rapid decline in temperature (e.g. at night time), since the grain itself is an excellent heat insulator, and temperatures within the grain mass will change only very slowly. From a psychrometric chart (Figure 5.3) it can be seen that air at 65% RH and 25°C will need to cool to 18°C before reaching its dew point. Cooling rates can be quite rapid with steel surfaces, however the air inside will lose its heat mainly through convection which will be much slower. In the process, the RH of the cooled air will be reduced by grains at the surface absorbing water vapour. It should be noted that only very small quantities of water are involved, and that the change in grain moisture content will be very small. Even if condensation on the underside of the roof was to occur, the amount of water that would be deposited would be very small. For instance, a 40 metre diameter tank silo with 1 metre of head-space above the grain has a head-space air volume of around 1500 cubic metres. If the head-space air is initially at 25°C and 65% RH, and it cools to 10°C without moisture absorption by the grain, then (from the psychrometric chart) the initial air moisture is 13 grammes per kilo-gramme of dry air, and the final moisture is about 8 gm/kg. From this it can be calculated that the amount of moisture condensing would be around 9 kg, or enough to raise the moisture content of the top centimetre of

Figure 7.12. Oil-bath and Diaphragm-type pressure relief valves.



Oil bath type pressure relief valve.



Diaphragm type pressure relief valve

grain by 0.08%. Where bins are only partially filled with grain (i.e. where there is a large head-space volume) there is potential for an increased amount of condensation. However the total amounts of water remain low provided the store is sealed and not open to entry of moist air from outside.

Experience in Australia suggests that problems with condensation do not occur in sealed stores when the grain is kept at or below its safe moisture level. Problems will occur if grain moisture levels are high, or if insect infestations occur, since in both circumstances biological activity will cause a localised increase in temperature and moisture content. This creates thermal instability in the grain mass, resulting in a convection movement of air and moisture which in turn enlarges the volume of affected grain. This chain reaction can ultimately result in massive spoilage with wetting and crusting of the grain surface if not controlled. Crusting is likely to occur whether the store is sealed or not, the problem emanating from within the grain mass itself, and is a result of poor storage management. Sealable storage provides a management tool which can be used to reduce the risk of such occurrences.

Moisture diffusion is not the same as moisture migration. It will occur in a grain mass in which temperature differentials exist for extended periods of time, such as when warm grain is kept in storage during cold winter conditions. This has sometimes been reported to cause condensation problems in sealed stores. It may be noted that diffusion is a physical process of moisture and heat **redistribution**, which is quite separate from moisture migration resulting from insect or fungal 'hot spots' which are heat **generating**. Such situations are, however, better handled by aerating the grain to equalize temperatures, than by selecting ventilated (or unsealed) structures for grain storage. It may be noted that without aeration, average temperatures in a grain bulk will follow average outside temperatures with a delay of 2 or 3 months, depending on the size of the bulk.

Methods of Sealing

The easiest stores to seal are fully-welded steel silos, since the structure is effectively sealed by virtue of its welded construction. Concrete silos can also be sealed with ease provided joints are properly detailed, and care is taken to prevent cracking of the walls (as discussed above). In either case (with both steel and concrete silos), attention is needed to the design of openings in the structures: grain inlets and discharge valves, man access doors, etc. These must be fitted with suitable gaskets to ensure sealing when closed. Sealable discharge valves require careful detailing, since they also have to withstand grain pressures. Various methods are commonly used which overcome this problem (Figure 7.13).

As discussed earlier, bolted light-gauge steel bins, and other similar structures such as steel sheds and warehouses, are less easy to seal unless special care is taken during design and construction to ensure that all bolts are fitted with suitable sealing washers, and joints between adjoining plates are carefully sealed with appropriate sealants. Silicone sealants are well suited to sealing surfaces which are to be fixed together, such as overlapping sheets of iron. Silicones should be 'neutral cure' type which will not cause corrosion of the steel surfaces. Joints between roof and wall require special detailing to minimise the gap between them to allow easy sealing (Figure 7.14).

Figure 7.13. Two alternative arrangements (schematic) for sealing silo discharge valves. **A**, a valve plate which can be lifted to seal against the silo base; and **B**, a flexible seal attached to the silo base which can be tightened down against the valve plate.

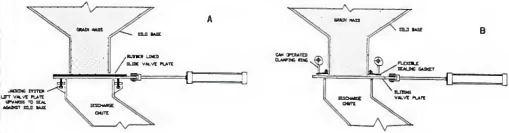


Figure 7.14. Wall to Roof Joint Seal. Light gauge flashing has been attached to bridge the gap betweer. wall and underside of roof. The flashing has been sprayed with polyurethane foam, which has been coated with a high-build flexible acrylic sealant coating.

Another method of sealing of joints, particularly when retro-sealing structures, involves the use of high-build "co-polymer" acrylic coatings. These are easier to apply than silicone sealants, and can be either brush or spray applied. High quality coatings can bridge small gaps, and will remain flexible enough to accommodate movements over a long period of time. This is particularly useful for sealing existing joints which cannot be opened easily for the application of silicone type sealants. Acrylic coatings require minimum surface preparation and can be applied over concrete to seal cracks, and also to steel surfaces to seal over joints.

When gaps are wider than about 2mm, acrylics perform better if a flexible fabric 'bandage' is used as a bridging medium to support the coating. This is especially the case if relative movements across the joint are likely.

Joints with gaps wider than about 10mm can be sealed with closed cell polyurethane foam, which can be spray-applied over adjoining surfaces to act as a bridging medium. In the case of very wide gaps, solid infill such as light gauge steel can be used in combination with other sealants. Polyurethane application involves spraying of two liquid chemical components which, when mixed together in the spray gun, expand on contact with the air to form a rigid foam.

Testing for Gas-Tightness

Testing of stores for gas-tightness should be carried out when they are commissioned. It should also be carried out routinely each time a fumigation is to be undertaken. The standard gas-tightness test was evolved by the CSIRO Stored Grain Research Laboratory, Australia, in the early 1970's and has proved an easy and effective means of determining the suitability of stores for effective fumigation.

The test involves applying a positive or negative pressure differential between the inside and outside of the sealed structure, for instance by means of a small fan or air compressor. Once the test pressure is reached, the air supply is cut off (and sealed) and the drop pressure recorded over a period of time. The acceptance criterion for an empty store is that the time taken for the pressure to drop to half its initial value (its half-life decay time) should be not less than 15 minutes. For a full store the time should be not less than 8 minutes. Test pressures are normally in the range of 0.75 to 1.5 kPa, depending on the strength of the structure being tested. Tests should be carried out at times of relatively constant air temperature so that pressure decay periods are not affected by temperature generated pressure variations.

It may be noted that the pressure decay standard is independent of storage volume. The standard is thus much more tolerant of air-leaks in large stores than in small ones. It can thus be deduced that small stores are more difficult to seal than large ones, since much more attention has to be given to sealing of small leakage paths. Nevertheless, farm-bins of 50 and 100 tonne capacity are often sealed in Australia, and a growing market exists there for sealable bins sold by small-bin manufacturers.

AERATION

Ambient Aeration

Aeration is a process of forcing air through grain to reduce its temperature. It is a very useful storage management tool which can preserve grain from deterioration, especially where the moisture content of the grain is above its safe level. Aeration can be used as effectively in sealed stores as in unsealed ones - sealed stores merely requiring the provision of an air-exhaust ventilator which can be sealed whenever fumigation is to be carried out.

In terms of storage design, the requirements for ambient aeration are simply (a) to provide some form of perforated ducting on the floor through which air can be blown into the grain, and (b) venting above the grain for air exhaust. (With downwards aeration the floor ducting is used for exhausting the air and the roof opening is the air inlet.) Floor ducting can be in the form of corrugated circular or semi-circular ducts on top of the floor surface, or troughed ducts flush with the floor surface. The latter are more costly, but allow for easier removal of grain from horizontal floors.

Good design of aeration systems is essential for efficient cooling. For instance, ducts must be of adequate size for the required air-flow, and should be located to ensure good distribution of cooling air throughout the grain mass. In general, duct sizes should be such as to limit air velocities to no more than 10 m/s, and duct surface area should be sufficient to limit air velocity at the duct/grain interface to around 0.2 m/s. Detailed discussion of duct design is beyond the scope of this bulletin. However, besides the many papers on the subject, there are now several computer software packages which can be used for their design.

Reducing grain temperatures by aeration offers numerous benefits. It reduces the rate of insect population growth; it reduces the rate of microbial (or mould) development; it preserves germination viability and it prolongs the effectiveness of insecticide chemicals where these are used. If temperatures can be reduced low enough (to around 10°C wet bulb), insect population growth rates can be stopped altogether. In all cases, it is the wet-bulb temperature which governs the benefits that can be achieved from aeration cooling.

It is apparent that ambient aeration requires periods (e.g. at night time) of low wet bulb temperature to effect cooling of the grain. Such conditions are not always available in tropical climates, particularly during the wet season. The major requirement during such times is more often on drying rather than cooling, however where aeration cooling is required or warranted (for instance after drying, or to delay mould development prior to drying), some air cooling and/or dehumidification may be needed to achieve the requisite conditions (see below).

To be effective, aeration requires the use of a well defined strategy and a good control system for operation of the fans. Where these are not effective, aeration can result in high costs for little or no gain, and can even be counter-productive. The key to successful aeration, is to design the cooling rate to minimise grain spoilage. For instance in the case of high moisture grain, it may be beneficial to begin with high rates of aeration to achieve a modest temperature reduction so as to delay the onset of fungal activity. Subsequently a

reduced rate of aeration can be used to achieve further temperature reductions at a slower rate. Selection of appropriate ambient air to achieve optimum temperature loss is the basis of aeration strategy.

When air is forced through a grain mass, it carries with it first a 'temperature front', and then a 'moisture front'. The temperature front moves quite rapidly, while the moisture front moves very slowly. Above the temperature front, the grain remains at its initial temperature and moisture level; below it the grain is at the wet-bulb temperature of the aeration air. Below the moisture front, the grain is at the same RH as the aeration air. With aeration, the aim is to ensure that the temperature front is a cooling front, and that heating fronts are largely avoided. Ideally, aeration air should also be selected to avoid the creation of wetting fronts, however at normal rates of aeration the speed of the moisture front is so slow that wetting problems seldom cause more than very localised damage.

The speed of the temperature front is governed largely by the rate of air-flow, and the temperature of the aeration air. Surprisingly, it is largely independent of the initial grain temperature. To design an aeration system, it is necessary to know (approximately) the climatic conditions so as to define the condition of the ambient air that is likely to be available for grain cooling. Also the initial temperature and moisture levels of the grain need to be known, so as to determine the maximum time that can be allowed for the cooling front to pass through the grain before deterioration begins. Given these factors it is possible to calculate fan and duct sizes, and to predict the performance of the system in operation. As already stated, several software packages are now available which can be used to perform the calculations and produce an optimum design for fans, ducts, etc.

Numerous control systems are available for controlling fan operation, some being relatively simple, and others more complex. Most are based on micro-processing technology, and they differ principally in the degree of sophistication in the monitoring systems that they use. One of the simplest (yet effective) systems is the 'set-point' controller which monitors only dry-bulb ambient air temperature. It is designed to provide a predetermined amount of aeration (in terms of the number of hours per week that the fans will operate) by automatically adjusting the minimum 'set-point' air temperature at which the fans will start. By continuously monitoring air temperatures and fan operating hours, the controller calculates the optimum periods for aeration to achieve maximum temperature reductions, whilst ensuring a predetermined number of fan hours per day. The number of fan-hours of aeration can be adjusted manually; by reducing the fan-hours, the controller is able to select colder air to achieve lower grain temperatures, however the time taken to cool the grain will be increased. The strategy for grain stored at high temperature is thus to begin with 'rapid' aeration during which the controller select the coldest air whilst achieving fan operation for (say) 50% of the time until the cooling front has passed through and the entire grain mass has been initially cooled. This may take a week, depending in the air-flow rate. The controller is then adjusted so that the fans to operate only during the coldest 15% of the time. This will cause a further reduction in temperature (of maybe only 2 or 3 degrees), however this cooling front may take a month to pass through the grain.

More sophisticated (and more expensive) controllers may measure not only dry and wet-bulb air temperature, but grain temperatures as well. Such systems can ensure that aeration will only occur when ambient air is sufficiently cool to maintain a cooling front - i.e. by avoiding

all air that is warmer than the grain. Such a strategy will provide no aeration at all at times when air temperatures remain above grain temperature. This may not be a problem if the grain is dry and insect-free, but it could result in major problems if localised heating goes undetected.

Refrigerated Aeration

Aeration with refrigerated air achieves much lower temperatures when ambient conditions are warm. It is an expensive method of disinfestation compared to fumigation, but can be justified for storage of grains such as malting barley and seed grains in hot conditions, where maintenance of germination viability is important. Technically, the requirements are the same as for ambient aeration, except that no fan control is required since the system will operate 100% of the time until the temperature front has passed through the grain mass. An evaporative cooling system is used to reduce air temperature and to remove moisture. It is useful to place the fan between the cooling unit and the store, so that heat from the fan can be used to raise the air temperature by a few degrees, thus reducing its relative humidity and minimising risk of grain wetting.

By recirculating the cooling air, it is possible to maintain a sealed storage system. In this way the grain may first be fumigated to render it insect-free, and then cooled to preserve quality, with the fumigant still present.

COSTS OF BULK STORAGE

As a rough rule of thumb, the costs of modern bulk grain storage and handling facilities can be broken down roughly as follows:

Storage Component:	40 to 60%
Structures and Supports	10 to 20%
Mechanical Equipment	20 to 40%
Electrical and Controls	10 to 20%

Obviously, there are many instances where storage costs are much less than 40% - for instance in high throughput facilities where the 'storage' component is no more than a short-term buffer to allow optimisation of the use of the handling equipment.

But in true 'storage' situations, where the purpose of the facility is to hold grain for an extended period of time, it is generally the case that the storage structures account for the largest component of the total cost. Thus it is normal practice to develop a design for a grain handling facility around the storage component; in other words to estimate the storage volume required, evaluate the type of store best suited to the requirements, and then to design the conveying and other systems to suit.

The cost of a store depends to such an extent on 'unit size' (i.e. the size of each individual bin or storage unit) and on locality (i.e. cost and availability of labour and materials), that the optimum solution for one given set of circumstances may be quite different to another. However as a rule of thumb, the following points may be helpful (based on 1992 costs):

* Bunker storage is the lowest cost storage available. It is also the quickest to build, and thus provides an ideal solution for emergency storage purposes. The construction cost can be as low as US$2.00 per tonne, depending on topography, drainage requirements etc. Operating costs can be high, and are to a large extent dependent upon the local cost of labour. Plastic covers may cost as much as US$2.00 per tonne or as little as US$0.50 per tonne, depending on material used. Heavy duty PVC covers can be expected to last three or more seasons (depending on the rate of Ultra Violet degradation), while lighter weight polyethylene covers are best replaced each season.

* The larger the size of a storage unit, the lower is its cost per tonne of capacity; current prices for large (greater than 5000 tonne) tank stores in developed countries are in the range of $US25 to $US35 per tonne, excluding handling equipment. Smaller tanks of 1000 or 2000 tonnes capacity may cost $US40 per tonne.

* In terms of cost per tonne, flat bottomed tank storage is generally cheaper than sheds or warehouses, even for stores of 20,000 to 30,000 tonnes capacity. There are few instances where unit volumes larger than this are justified, bearing in mind the difficulties of segregating grain in warehouse type stores.

* Tall hopper-bottom silos are cost justified in high throughput situations, but their cost (per tonne) is likely to be at least twice that of tank storage. Costs of $75 to $100 per tonne (or more in some instances) can be expected.

* The extra costs associated with building sealed storage facilities are negligible if they are properly designed.

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CHAPTER 8

INSECT CONTROL

INTEGRATED PEST MANAGEMENT (IPM) IN THE CONTROL OF STORAGE INSECTS

The characteristic problems of stored-grains pest control in the tropics, with particular reference to developing countries, are concisely described by Taylor, Golob and Hodges (1992). They indicate the crucial importance of effective pest control for a broad range of storage entrepreneurs, including resource-poor farmers, commercial operators, and national marketing organisations; and a wide variety of storage situations in which simple, traditional on-farm systems and large scale bag-storage systems predominate. Bulk storage occurs quite commonly for small bulks, at farm level; but is less common than bag-storage in large scale operations except at large grain mills and at some central marketing depots.

Pest control measures, in general, have to be integrated into an operational system, be it large or small in scale, if they are to be effectively applied. This is a basic principle, not a novel concept, but it connects well with the modern idea of Integrated Pest Management (IPM). The use, in that term, of the word 'management' is appropriate, especially with regard to the need for the integration of pest control measures into management systems, but it should be remembered that the two words, 'management' and 'control', are almost synonymous. The fundamentally important emphasis should be placed upon the word 'integrated'.

Integrated pest control can be defined as the acceptable use of practicable measures to minimise, cost-effectively, the losses caused by pests in a particular management system. For the measures to be cost-effective they must be appropriate to and acceptable into that system. They may be simple or complex but they must suit the system objectives and its technical capabilities. Furthermore, in this context, cost-effectiveness requires that all costs and benefits, including sociological and environmental effects, should have been taken into account.

The term integrated pest management is used to imply that a flexible and technically informed approach is also required. In defining this term it may be considered necessary (McFarlane, 1989) to specify the inclusion of scientific and cost-effective pest monitoring procedures which permit judicious adjustments to the timing, choice and intensity of control actions. It may also be advisable to point out that specific pest control measures, as distinct from general crop or commodity husbandry practices, should generally be omitted unless the circumstances warrant and permit their cost-effective inclusion.

Insect pest management for stored grains, like preharvest pest management, can thus be seen, historically, as a traditional approach in which good husbandry is the primary requirement. Unfortunately, it must also be acknowledged that the advent of readily available, relatively

inexpensive synthetic insecticides has led to considerable over-dependence upon these hazardous tools with, in some cases, a consequent neglect of basic good husbandry. The current emphasis upon integrated pest management is, in effect, a reassertion of the need to put traditional good husbandry in place as the fundamental basis of pest control. In grain storage, as with other durable agricultural products, it is good commodity management and good store management which are the major prerequisites (Tables 8.1 and 8.2).

The various options for more intensive insect pest control, which are also listed in Tables 8.1 and 8.2, include several which are themselves based upon traditional concepts of pest management. Thermal disinfestation, cooling and hermetic storage are examples. These latter two methods are also examples of the opportunities, provided by the process of storage, to manage the generally enclosed storage environment in such a way that insect pests are prevented from multiplying or, as in efficient hermetic storage, effectively eliminated. Preharvest problems of insect pest control are rarely, if ever, so easily managed!

Control of the storage environment is thus an essential element in grain storage pest management. It involves, primarily, the controls on in-store climate and infestation-pressure which can be achieved by technically sound store design and construction. Equally important, however, is the climatic control attainable by scientific management of the commodity to ensure that the stored grain is itself both dry and cool when loaded or, in ventilated stores and bins with aeration equipment, that the storage procedure achieves drying and cooling sufficiently rapidly. In a fully loaded store it is the stored grain itself which largely determines and stabilises the temperature and humidity conditions in the store.

Commodity management can also control, to a considerable extent, the initial insect infestation level in the stored grain. However, in tropical countries, where preharvest infestation by storage insects is hardly ever completely preventable, the ideal of loading insect-free grain into the store is not often attainable. Special facilities to completely disinfest the grain before loading may not prove cost-effective. The common alternatives, if early disinfestation is required, are to treat the grain, at intake, with a suitable admixed insecticide or to disinfest the loaded grain by in-store fumigation.

Control of grain quality before storage, to minimise the intake of heavily infested and badly damaged or uncleaned grain, is feasible and is commonly practised to a considerable extent. Even at the small farm level it is possible to segregate the crop at harvest, especially with maize on the cob and unthreshed sorghum and millet, selecting relatively undamaged material with good storage potential and setting aside the more evidently infested or otherwise damaged material which, if there is no other option, can at least be used first. By such means, the rate of deterioration due to insect infestation can be considerably retarded in the main stock of stored grain. There is little doubt that some subsistence farmers use this form of commodity management fairly effectively. Certainly, one can sometimes observe on-farm grain stocks, that have received no special insecticidal treatment, with relatively little insect damage after several months storage at an ambient temperature that would permit the rapid increase of any well-established initial insect population.

Scientific approaches to grain storage pest management, having regard to grain storage as a part of the food production and distribution management system, have sometimes referred

Table 8.1. Prerequisites and options for on-farm storage pest management

Essential	Optional
Basic IPM	**Additional measures**
Site and store management (protection from birds, rodents and weather plus basic hygiene)	Maintenance of conditions favourable to natural control: - by cooling (where feasible) by insect parasites, pathogens, etc. and/or Thermal disinfestation by solar heat and/or Treatment with traditional additives (if sufficiently avaiable and effective)
Commodity management (cleaning, drying, etc.)	or Treatment with synthetic insecticides (if suitable formulations sufficiently available and effective) or Hermetic storage (pits or metal drums, etc.)

Table 8.2. Prerequisites and options for storage pest management at main depots

Essential	Optional	
Basic IPM	**Disinfestation**	**Prevention of reinfestation**
Site and store management	Insecticide admixture[*!]	Provided by the treatment
(protection from birds, rodents and weather plus	Fumigation[!]	Residual insecticide sprays[?!] or
basic hygiene)	Thermal[*!]	Physical protection[!] (Sheeted stacks or packaging) or
Commodity management (cleaning, drying, etc.)	Irradiation[*!]	Insecticidal space treatments[!]
- with bulk storage	Hermetic[!]	Provided by the system
if appropriate	Controlled atmosphere[!]	Provided by the system
	Grain cooling[!]	Provided by the system

Notes:

[*]May entail double handling for in-bag storage. [?]Efficacy doubtful. [!]Extra management skills and/or other inputs required.

to the biological ecosystem concept as a means of comprehending grain storage processes and problems. In a recent contribution Dunkel (1992) has applied ecosystem principles in a broad analysis directed towards an improved understanding of physical and biological interactions including socio-economic factors. The purpose was to generate improved understanding of the stored grain ecosystem and to identify objectives for future postharvest research. This treatment of the subject should serve to enhance the growing awareness of storage as a system within a system and to stimulate systematic and objective analysis of grain storage problems. Whether or not one prefers to use the term 'ecosystem' is less important and this somewhat academic term should not be allowed to obscure the main issues.

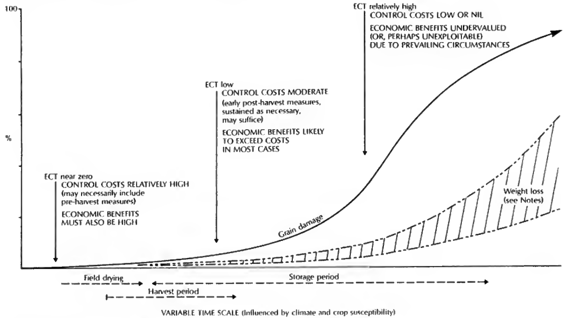
The integration of various control techniques, within the framework of integrated pest management, has become a focus for research in stored products work (Evans, 1987a). The importance of a multidisciplinary approach to stored grain research has also been stressed (White, 1992). This is very valid but it is useful to recall that a great deal of the research done in the past has been of this nature. It was pointed out (McFarlane, 1981), at a stored products pest management symposium held in 1978, that the need for an interdisciplinary approach is generally well-known. Entomology, mycology, chemistry, engineering and food science are commonly involved, but effective integration of technical solutions is often lacking; possibly because some of the more pragmatic disciplines, notably economics, sociology and business management, are not always sufficiently involved. It is the interface between the research team and the storage managers, whether these be individual farmers or a large storage organisation, which may sometimes be the most crucial barrier to progress.

A clear perception of the need for solutions which can be integrated into the management system, because they meet the business objectives and can be accommodated within existing management capabilities, is probably the most important requirement (Hindmarsh and McFarlane, 1983). In this context it is of some interest, although not very surprising, that a correlation has been found amongst farmers in India between 'grain hoarding capacity' (which relates to the farmers' existing business objectives and capabilities) and the adoption of improved storage practices (Thakre and Bansode, 1990).

Modern theories of pest management have also generated the concept of economic control thresholds (ECTs). An ECT is most simply defined as the level of pest damage which justifies, in cost/benefit terms, the expenditure of resources upon control actions (Hebblethwaite, 1985). It is always a variable threshold because the costs and benefits of any action will depend upon the situation and its circumstances. An ECT is situation-specific. This is especially true, and not only for postharvest pest control, when one considers the great differences in opportunities and constraints between the small farm level in developing countries and more sophisticated levels of operation. Nevertheless, it is possible to generalise to some extent (Figure 8.1). For insect control in grain storage the ECT is likely to be at or very close to zero:

(a) where consumer demands place a high value on freedom from insect damage and/or freedom from any sign of insect infestation;

Figure 8.1. Conceptual control thresholds for insects on stored grains



Notes: Weight loss per damaged grain is dependent upon pest species and grain type: e.g. 90% grain damage by weevils and secondary pests is equivalent to about 20% weight loss in maize (McFarlane, 1975) but substantially more in wheat and rice.

Loss in market value is dependent upon consumer requirements and grain type.

(b) where there is a definite intention to store grain for a protracted period, in which substantial insect damage can be predicted, and where the eventual market is not insensitive to loss of quality.

In both cases the assumptions are made that at least one potentially cost-effective package of control measures is available and that the package provides for sustained control: including efficient prevention or control of reinfestation. In most sophisticated situations, where consumer quality standards are likely to be high, these will be valid assumptions. Otherwise the ECT could not be zero and the required quality standards would have to be met by reconditioning the product. The losses, including reconditioning costs, would then have to be borne by the system or the consumer. A real economic loss would have occurred, masked by marketing tactics. Such events do, undoubtedly, take place.

Where grain is being stored for domestic use, or for eventual sale in an uncritical market, the ECT may be well above zero. This can be true even when all parameters of economic damage are considered because, in fact, the true economic significance of a low percentage of insect damaged grain may be virtually nil. The actual loss in real food value is likely to be negligible and the market value of the associated weight loss, if saved, may not offset the full costs of pest control actions.

The need to minimise the cost of insect pest control is a major factor militating against the extensive use of some of the more 'environmentally friendly' measures which might otherwise be preferred to the continued use of suitable fumigants and contact insecticides. However, it must also be acknowledged that chemical pest control measures, in grain storage, are often not only the cheapest but also the most reliably efficacious of the possible options. Where this remains true, and for as long as such treatments are accepted as generally safe, one important requirement for IPM in grain storage will be to ensure that chemical measures are recommended only where they can be safely and efficiently used and only when they are economically justifiable.

The economic justification of control measures, including where necessary the use of chemical pesticides, should take account of all costs and benefits. Many of these may be assessable only in subjective terms that are greatly dependent upon local attitudes and sensibilities. However, measurable losses of quantity and certain quality parameters can be objectively determined. A manual of methods for the evaluation of postharvest losses (Harris and Lindblad, 1978) is available and provides useful information, subject to a need for modification of some methods in particular circumstances. A critical review of the methodology (Boxall, 1986) gives further guidance based upon experience gained, since 1978, from field work in many developing countries. Choices among methods, several of which have become subjects of considerable controversy, should always be made with due regard to the actual circumstances and the prevailing objective. There is no single 'best method' for all circumstances and, for practical purposes, operational facility and repeatability are generally more important that fine precision. From the storekeeper's viewpoint a demonstrable loss reduction from, say, 5% to 4%, however statistically significant, may be of little or no practical importance; whereas a reduction from 10% to 5% (or from 2% to 1% in a sophisticated storage system) may be of considerable interest: provided, always, that the demonstrated reduction can be achieved in routine practice.

INSECT PESTS OF STORED GRAINS IN HOT CLIMATES

The insect species of most importance in the tropics as pests of stored foodgrains, including pulses (legume grains), are listed in Table 8.3. Recognition of these common major pests, at least to the genus level, is not difficult for a trained inspector and there are many useful recognition charts and some excellent keys to specific identification. One of the most recent is contained in a Training Manual "Insects and Arachnids of Tropical Stored Products: their Biology and Identification" produced by the Natural Resources Institute (Haines, C P [ed], 1991). This publication also contains summarised biodata for important species. Another, by Weidner and Rack (1984), may be more useful in francophone countries.

There are many other publications which illustrate the common insect pests of stored products and describe their biology. The familiar details are not all repeated here. Instead, the points which seem of particular importance with regard to pest status are discussed more broadly.

Table 8.3. Important insect pests of tropical stored grains or grain products

COLEOPTERA:	ANOBIIDAE	*Lasioderma serricorne* (F)
	BOSTRICHIDAE	*Rhyzopertha dominica* (F)
		Prostephanus truncatus (Horn)*
	BRUCHIDAE	*Acanthoscelides obtectus* (Say)
		Callosobruchus spp.
		Zabrotes subfasciatus Boheman
	CUCUJIDAE	*Cryptolestes* spp.
	CURCULIONIDAE	*Sitophilus oryzae* (L)
		S. zeamais Motschulsky
	DERMESTIDAE	*Trogoderma granarium* Everts**
		Dermestes spp.
	SILVANIDAE	*Oryzaephilus surinamensis* (L)***
	TENEBRIONIDAE	*Tribolium castaneum* (Herbst)
LEPIDOPTERA:	GELECHIIDAE	*Sitotroga cerealella* (Olivier)
	PYRALIDAE	*Ephestia cautella* (Walker)
		Plodia interpunctella (Hübner)
		Corcyra cephalonica (Stainton)

Notes:
*Now established in Africa as well as in the Americas. **Common only on very dry grain; especially in Sahelian North Africa. ****O. mercator* (Fauvel) may also occur but is more commonly a pest of oilseeds.

The grain weevils (Curculionidae) are well-known as major primary pests of stored cereal grains. They are able to establish themselves on whole, undamaged grains of maize, sorghum, rice and wheat so long as the grains are not exceptionally dry. However, *Sitophilus zeamais* is the dominant species on maize while *Sitophilus oryzae* is dominant on wheat. Neither species is a significant pest of millets and other grains that are too small to permit the full development, within a single grain, of the weevil larva.

The bostrichid beetle *Prostephanus truncatus* (the Larger Grain Borer) is a highly destructive primary pest of maize, especially maize stored on the cob. This insect is now established in several East and West African countries following recent accidental introductions from its previously more limited indigenous range in meso-America (Dick, 1988; Golob, 1988; McFarlane, 1988a). The Lesser Grain Borer (*Rhyzopertha dominica*) is more cosmopolitan and is well-known as a destructive pest of most stored cereal grains including millet. It is not generally common on maize.

The bruchid beetles listed in Table 8.3 are the only significant pests of stored pulses. *Acanthoscelides obtectus* and the less cosmopolitan *Zabrotes subfasciatus* are generally restricted to dry beans (*Phaseolus vulgaris*) while *Callosobruchus* spp are generally restricted to the other legume grains, notably cowpeas and mungbeans (*Vigna* spp). The anobiid *Lasioderma serricorne* is sometimes reported as a significant pest of stored beans and other pulses but it is not a primary pest of foodgrains. It is, however, a considerable pest of cereal-based animal feeds, wholemeal flour and high-protein milling offals.

Apart from the one exception noted above (*L. serricorne*) all of these beetles are primary pests in the sense that they can initiate major damage to the grains and most of them are also able to commence their attack in the field before harvest. The other beetles listed in Table 8.3 are generally regarded as secondary pests which can be of major importance on grains previously damaged either mechanically or by other insects. The dermestid *Trogoderma granarium* is exceptional in that it can cause major primary damage but rarely occurs as a primary pest except in arid climates, or on very dry grain, where other primary pests are inhibited by the dryness.

Of the moths (Lepidoptera) listed in Table 8.3 only the gelechiid *Sitotroga cerealella* is able to cause substantial primary damage to the grain kernel. Like the grain weevils it can also infest the grains before harvest and like the Lesser Grain Borer it is a considerable pest of millets as well as all the larger cereal grains.

The other moths listed are warehouse moths, and the rice moth *Corcyra cephalonica* is included here although it is less commonly abundant on other cereal grains. The larvae of all three species can do substantial damage as secondary pests. They can also attack the whole grain at the site of the embryo, which is typically excised completely, and may thus be of special importance as pests in seed grain stores.

Many other insects may occur quite commonly and sometimes abundantly on stored cereal grains especially when they are underdried or have been heavily infested by the major primary and secondary pests. Some of these are listed in Table 8.4. This list, although quite extensive, is not exhaustive. Most of the species included are capable of doing some damage to the grain and while several are unable to thrive in the absence of mould growth, or are most commonly predators and scavengers rather than grain feeders, their presence would be unacceptable to many consumers. Evident signs of their previous activity, in the form of insect fragments and waste matter, will be equally unacceptable where high quality commands a premium price.

Table 8.4. Insect species (additional to those in Table 8.3) found on underdried stored grain or grain residues

COLEOPTERA:	ANTHRIBIDAE	*Araecerus fasciculatus* Degeer
	BOSTRICHIDAE	*Dinoderus* spp.
	BRUCHIDAE	*Bruchidius* spp., *Specularius* spp.
	CLERIDAE	*Necrobia rufipes* Degeer
		Thaneroclerus buqueti Lefevre
	CRYPTOPHAGIDAE	*Henoticus californicus* (Mann)
		Cryptophagus spp
	DERMESTIDAE	*Attagenus* spp., *Dermestes* spp.
	LATHRIDIIDAE	*Corticaria* spp., *Lathridius* spp.
	MYCETOPHAGIDAE	*Typhaea stercorea* (L)
	NITIDULIDAE	*Carpophilus* spp.
	OSTOMIDAE	*Tenebroides mauritanicus* (L)
	PTINIDAE	*Ptinus* spp.*, *Trigonogenius* spp.*,
		Gibbium spp.
	SILVANIDAE	*Cathartus quadricollis* (Guerin)
	TENEBRIONIDAE	*Alphitobius* spp., *Gnatocerus* spp.
		Palorus spp.
LEPIDOPTERA:	OECOPHORIDAE	*Endrosis sarcitrella* (L)
PSOCOPTERA:	LIPOSCELIDAE	*Liposcelis* spp.

Note: *Common only in cool upland tropics.

The psocopteran (psocid) species listed in Table 8.4, which include the familiar 'dust lice', sometimes mistaken for mites (Acarina), have received more attention in recent years than previously; both in the tropics and in temperate countries. In the latter, they have attracted attention as occasional pests of various commodities including skimmed milk powder. In the humid tropics they sometimes occur as troublesome pests of cereal grains, notably milled rice, on which they are sometimes very abundant (Rees, 1990). It has been shown that a psocid population can feed and multiply on damaged or imperfect cereal grains (Shires, 1982). When milled rice is exposed to very dense populations the feeding damage, on some individual kernels, can be massive (McFarlane, 1982). Whether or not such damage occurs sufficiently extensively to constitute an economically significant weight loss in storage practice has yet to be demonstrated. However, it has been shown (V. Pike, personal communication) that measurable weight losses can occur, especially on under-milled rice, and that the protein and lipid content of the infested rice may be reduced. The nuisance-value of these small insects, when they occur as dense, swarming populations in warehouses, is also considerable. Furthermore, surface scarification due to psocid feeding may improve the apparent whiteness of infested milled rice and thus obscure the visible evidence of mould growth and possible contamination by mycotoxins.

Pest status

The status of any particular insect pest may vary between different commodities, different varieties of the same commodity, different climatic regions and agro-industrial systems and between different socio-economic groups. It is affected by the form in which the commodity

is stored (Figure 8.2), by the environmental conditions and by consumer attitudes. As with the psocid problem, referred to previously, it may also be affected by the sensitivities of store supervisors and their work-force.

Figure 8.2. Pest status as affected by handling and processing.

Pest	Preharvest	Unshelled	Shelled	Milled: kernels	flour	Offals
S.zm	**	***	*****	****	*	
S.o	*	***	*****	****	*	
S.c	**	****	***	**		
P.t	**	*****	***	*		
R.d		**	****	**	*	
T.c etc	*	*	**	***	****	*****
E.c etc		*	***	***	****	*****
L.s			*	*	*	****
A.o	***	***	*****	***	*	
C.spp	***	***	*****	***	*	

Key

S.zm	*Sitophilus zeamais*	- on maize, sorghum and rice
S.o	*Sitophilus oryzae*	- on wheat, sorghum and rice
S.c	*Sitotroga cerealella*	- on all cereals
P.t	*Prostephanus truncatus*	- on maize
R.d	*Rhyzopertha dominica*	- on all cereals
T.c etc	*Tribolium castaneum* & other secondary beetles	- ditto
E.c etc	*Ephestia cautella* & other warehouse moths	- ditto
L.s	*Lasioderma serricorne*	- on all grains
A.o	*Acanthoscelides obtectus*	- on beans
C.spp	*Callosobruchus* spp.	- on cowpeas, etc.

*	Very low status (possibly negligible)
**	Low status
***	Low - moderate status
****	Moderate - high status
*****	High status

Pest status may also vary between biotypes of the same insect species due to differences in the capacity to cause grain damage (McFarlane, 1990) or to adaptations to other foodstuffs. As an extreme example of this, although grain weevils are usually insignificant as pests of stored pulses there are biotypes of *S. oryzae* that multiply successfully on stored split peas (Holloway, 1986) and on mung beans (C P Haines, personal communication: including field records). Certain strains of *S. oryzae* have been noted as having greater flight proclivity than others (Kiritani, 1959). This species, unlike the maize weevil *S. zeamais*, does not usually fly very readily, although it has wings.

The influence of maize varietal characteristics upon the preharvest infestation of maize cobs by *S. zeamais* has been much investigated (Floyd and Powell, 1958; Giles and Ashman, 1971; Schulten, 1976). It is clear that the cob sheath, in those cultivars which produce sheathing leaves completely enclosing the entire cob, provides considerable protection against the weevil. Storage of cobs in the sheath, which does not significantly impair the grain drying rate in ventilated cribs, therefore reduces the status of the grain weevil as a pest and will be beneficial where weevils are the main threat (Dick, 1988). Even without the sheath, grains on the cob are considerably less susceptible to weevil attack than the shelled grains. The reasons for this have been clarified recently; by Kossou, Bosque-Perez and Mareck (1992). Unfortunately, maize on the cob, especially without the sheath, is more heavily attacked by the grain moth *S. cerealella*. The Larger Grain Borer *Prostephanus truncatus* is also favoured by storage on the cob, with or without the sheath. The impact of this pest in those African countries where it has recently established itself has been dramatic for this reason as well as on account of the more rapid and destructive grain damage caused by the adult borers (Golob, 1988).

The status of this new pest in maize-based farming systems in Africa, traditionally dependent upon cob storage as a modest pest management stratagem, has been such that pragmatic thresholds for control action are commonly exceeded (McFarlane, 1988a). In consequence, demonstrably cost-effective treatments of shelled maize grain with admixed powder formulations of suitable synthetic insecticides have been readily adopted in several regions where they were, formerly, less often used. As a further consequence, it may be that the overall insect control level has been considerably enhanced, since the recommended formulations are generally 'cocktails' of two active ingredients that can give effective control of a broad spectrum of storage insect pests (Golob, 1988).

The storage of sorghum and rough rice (paddy) in the panicle, millet on the head and cowpeas in the pod also serves as a modest form of insect pest management. However, the storage of unthreshed grains, although it may retard the build-up of infestation by some pests, does not prevent it entirely and different insects are affected in different ways. Thus, on sorghum, infestation by grain weevils is usually reduced but the grain moth *S. cerealella* is likely to be more successful (Giles, 1965; Wongo and Pedersen, 1990). On unthreshed rice and millet, for similar reasons, the grain moth will have increased pest status.

The low status of grain weevils as pests of millets and other small grains, previously mentioned, is due primarily to the limited grain size since the complete larval development, in these species, has to take place within one kernel. The lesser grain borer (*R. dominica*) and the grain moth (*S. cerealella*) are not so handicapped because their larvae are able to migrate, if necessary, from one kernel to another. However, the grain moth is a low status pest on large grain bulks and tightly-built large bag-stacks, where the beetles are serious pests, because the moth is unable to move freely amongst close-packed grains to lay its eggs and the first instar larvae are unable to travel more than a few centimetres in search of food.

Most storage insects, especially the important pests, are able to survive and multiply rapidly on well-dried grain. However, grain dried to below 12% mc inhibits the development of most species to some extent and on exceptionally dry grain (<8% mc) the grain weevils, for example, are insignificant pests. The grain borers remain of considerable importance at these low moisture levels and the "khapra" beetle (*T. granarium*) becomes increasingly important.

This insect assumes major pest status and dominance over almost all other storage insects at the very low moisture contents (down to about 4%) which equate to the extremely low humidities (< 20% rh) that characterise the most arid climates and, also, the insect ecosystem created by stored malting barley which is usually dried to this very low level and is not uncommonly imported into the tropics.

Factors affecting development and control

Grain moisture content considerably affects pest status but it is not a factor which can be cost-effectively manipulated, in most situations, to achieve sufficient control of insect pests. Cost-effective drying, in common practice, can achieve control of moulds and will lessen the problems of insect infestation; in particular it will greatly reduce the spectrum of pest species. However, it will not prevent significant damage by one or more of the major insect pests.

Insect development and population growth rates are more dramatically affected by temperature and here the developmental limits are more clearly defined and generally applicable. Upper limits for development and survival vary to some extent between species, with the grain borers again more resistant than the grain weevils, but temperatures above 45°C are eventually fatal to all storage insects. At 50°C most species will die quite quickly, within a matter of hours, and complete disinfestation of wheat grain can be achieved rapidly, economically and without damage to the grain by very short exposures to air heated to 60°C (Evans, 1987b).

Rapid insect development occurs within a fairly narrow range of 5-10 degrees around the optimal temperature which, for most storage insects, is in the region of 30°C. At temperatures nearer to 2O°C development proceeds more slowly and population growth may be considerably reduced. At 17°C or less it is relatively negligible and pest status is consequently greatly reduced. However, even at 15°C some species are able to continue feeding, to some extent, so that grain damage may very slowly increase. Insect populations will certainly not be eliminated at these temperatures and, while grain may often be held safely in cool storage, any eventual transfer to warmer conditions will bring about a resurgence of the suppressed infestation. Even in cold storage (at 6-9°C) some, at least, of the important insect pests of stored grain can survive longer than one year (Wohlgemuth, 1989).

Insects require oxygen for respiration. Living grains, when sufficiently dry (12-13% mc), are dormant and respire very little. Grain properties, including viability, are virtually unaffected in cool conditions by protracted hermetic storage. Insects, however, will use up the oxygen and eventually die. The traditional concept of sealed (hermetic) storage as a means of controlling insect infestation depends upon this. Most storage insects will die when the oxygen in the storage atmosphere is reduced, by the insects' respiration, to 2% (Hyde *et al.*, 1973). With light infestation the process may take 6-8 weeks but, if airtight conditions are maintained, the infestation will be controlled and probably eliminated before serious damage is done. There is new evidence (Donahaye, 1990) that insects may adapt to low oxygen tensions and evolve strains with considerable resistance to sub-optimal levels even down to about 1%. However, it seems very improbable that any storage insect would multiply rapidly in such conditions.

Physical disturbance of grain, by turning it from one elevator bin to another, can reduce live grain weevil infestation to a considerable extent and thus retard its further development (Joffe, 1963). A more complete kill of all insect life stages can be achieved, by mechanical high-speed impact, in the entoleters included in the processing line of many grain mills. In small-scale storage it may be less easy to achieve the degree of disturbance necessary for effective control of grain weevil and other cereal grain insect pests, although very small quantities of grain held in small pots or gourds could be shaken sufficiently violently for this purpose. Bruchid pests of stored pulses may be particularly susceptible to control by physical disturbance. In the bean bruchid *A. obtectus* this may be because the hatched first instar larvae require an approximately 24 hr period to penetrate the bean testa (Quentin *et al.*, 1991). These workers have shown that twice-daily 'tumbling' of small lots of stored beans, in partly-filled cylindrical containers, reduced bean bruchid populations by 97%. Daily sieving on a fair-sized coarse mesh can achieve similar results (M N Silim; private communication). However, the practicability of these proposed techniques, for routine use by farmers or traders in developing countries, is unproven.

Insect behaviour patterns may affect pest status and pest control. Examples have been given of the ways in which adult oviposition behaviour and larval feeding behaviour can affect pest status in the grain moth and pest control in bruchids. The development of infestations (pest population development) may also be affected by, for example, the diapause habit which characterizes several storage insects including, most notably, the khapra beetle *T. granarium*. Diapause may postpone population development, usually in unfavourable conditions, and it may also impair the effectiveness of control measures; including fumigation and the use of contact insecticides as surface sprays for 'clean-up' treatments in empty storages. Locomotory avoidance behaviour, especially in the flour beetle *T. castaneum* (Wildey, 1987), is also of considerable interest.

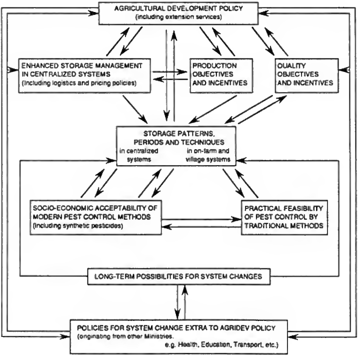
Storage management, which may be described as the science of cost-effective storage organisation (McFarlane, 1988b), greatly influences pest development and control. It encompasses decisions upon the location of stores, storage periods and the quality control objectives for stored commodities. All of these have substantial implications for pest management and are components of the complex interactive network of factors affecting loss reductions in grain storage (Figure 8.3).

Figure 8.3 draws attention also to socio-economic factors affecting, in particular, the acceptability of control measures. Modern techniques, especially those involving the application of synthetic insecticides to stored grain, are especially prone to consumer sensitivity. However, many traditional techniques face comparable problems. The use of wood ash and other supposedly non-toxic 'natural' grain protectants may not be acceptable in all circumstances, nor even to all those people at the small farm level in developing countries who are often supposed to prefer such treatments.

The insect resistance problem

The development by pests of acquired resistance or increased tolerance to pesticides is now a well-known pest management problem. It is coming to be recognised as not so much a remarkable phenomenon as an almost inevitable natural consequence of pesticide use. There is little doubt that much of the existing problem, which in recent decades has come to affect

Figure 8.3. Factor interactions and key issues for pest management and loss reduction in grain storage.



many species of storage insects and a wide range of insecticides (Champ and Dyte, 1976), stems from careless use. Resistance to phosphine fumigants in particular (Taylor, 1991) is almost certainly due in part to the not infrequent use of grossly inefficient application techniques.

There is general agreement that the rate of resistance development, in any particular pest species and to any particular pesticide, is to some extent susceptible to control (i.e. management). Possibilities for the containment of resistance include sustained improvements in application techniques, where acceptable pesticide dosage rates remain effective, and the adoption of alternative pesticides or other control measures where the degree of resistance to a particular pesticide prohibits its use. Continued monitoring of resistance, in field populations, is also necessary.

Concepts of reducing resistance by genetic control (Wool, 1975) have progressed to some extent (Wool *et al.*, 1992) and are not implausible. However, their practicality and cost-

effectiveness in stored-grains pest control remain undemonstrated. Moreover, it has been shown (McFarlane, 1990) that some resistant strains of several storage insects have a reduced capacity to cause grain damage, through an impaired population growth rate. There is no reason to suppose that all resistant biotypes will be less damaging than their susceptible counterparts but the monitoring of this capacity, in field populations, is feasible and seems worthwhile. Conversely, it would seem illogical to foster a reversion to susceptibility in cases where the resistant biotype has a substantially reduced capacity to cause damage and, therefore, a considerably reduced pest status.

The possibility that insects may develop resistance to other control measures has been noted already with regard to reports of increased insect tolerance to low oxygen tensions in controlled atmosphere storage (Donahaye, 1990). As in the development of pesticide resistance, considerable genetic flexibility is to be expected. However, one may also expect that insect adaptability to massive constraints on fundamental biotic requirements, such as aerobic conditions, will be more limited than their ability to exploit the more natural genetic potential for metabolising extraneous toxicants.

CHEMICAL CONTROL TECHNIQUES

General considerations

The chemical compounds, including both fumigants and contact insecticides, which are approved by FAO/WHO for use on food grains to control storage insects, are regularly reviewed. Their safety in use, for pest control operators and food-grain users, is carefully considered before approval is given and that approval may be withdrawn if new circumstances indicate the need for the exclusion of a particular compound. In general, the contact insecticides that are approved for use are compounds of relatively low mammalian toxicity, which are considered to be non-hazardous when applied at prescribed dilution rates for the purposes indicated. They are also relatively safer to handle than many of the pesticides quite commonly approved and widely used for preharvest pest control. Nevertheless, transportation and handling of the insecticide concentrates are hazardous. These hazards and the required precautions will be discussed further at the end of this section. At the outset, however, Tables 8.5 and 8.6 may be consulted for relevant data on mammalian toxicity, for a broad range of contact insecticides which are or have been used in the control of storage insects, and for the limits recommended by FAO/WHO for chemical residues, from contact insecticides and fumigants, in grain and grain products. It should be noted, in passing, that there is no acceptable residue for the insecticide DDT, which remains available in many developing countries but is no longer recommended for use in stored-grain pest control. Lindane, which is still of some use, is given a very low residue limit (0.5 ppm). This serves to preclude or discourage application to grains for export to countries which object to its use. It should also be noted that the limits for fumigant residues broadly represent the maximum levels that should be expected if fumigation treatments are properly done. This applies also to residues of inorganic bromide and these have recently been declared of no toxicological concern by the U.S.A's Environmental Protection Agency and by the British Government. The very low limit for phosphine in Table 8.6 reflects the generally negligible permanent residue which remains after the use of this fumigant.

Table 8.5. Acute mammalian toxicities (LD_{50} - mg/kg body weight) for contact insecticides currently of use in stored-grain insect control.

Insecticide	Rat (oral)	Dermal	Hen (oral)
Chlorpyrifos	135 - 155	202	32
Chlorpyrifos methyl	950 - 1,000	>2,000	>2,000
Dichlorvos	56 - 108	75 - 110	15
Fenitrothion	250 - 500	3,000	35*
Malathion	1,000 -1,400	4,100	-
Methacrifos	700	3,100	-
Pirimiphos methyl	2,050	2,000	30 - 60
Lindane	90	1,000	30 - 60
Bendiocarb	34 - 48	600 - 1,000	-
Carbaryl	500 - 850	4,000	2,000*
Dioxacarb	60 - 80	1,950 (3,000)	-
Propoxur	90 - 130	800 - 1,000	20*
Bioallethrin	500 - 860	3,500 - 5,000	-
Esdepaltethrine	800 - 1,500	1,500	-
Bioresmethrin	7,000	10,000	10,000
Resmethrin	1,400	3,000	-
Piperonyl butoxide	10,000		
Pyrethrum	580 - 900	2,000	
Tetramethrin	4,600 - 6,500	>4,000	5,000
Cypermethrin	250	>1,600	
Deltamethrin	130 - 140	>2,000	
Fenvalerate	450	>4,300	
Permethrin	1,500 - 4,700	>4,000	
Phenothrin	>10,000	>5,000	

Notes: The figures for oral toxicity are for rats or as specified. Dermal figures are for rats, rabbits or unspecified.
* Pheasants

Source: Pest Control for Food Security, *Plant Production and Protection Paper 63* (Prepared for FAO by ODNRI), FAO, Rome, (1985): with modifications.

Table 8.6. Maximum residue limits (MRL) and acceptable daily intake levels (ADI) (mg/kg or ppm) recommended by FAO/WHO as at April 1992.

Insecticide	Cereal* grains	Raw wheat bran	Whole meal wheat	Wheat flour	Milled rice	Dried pulses	ADI**
Lindane	0.5					0.5	
Malathion	8	20	2	2		8	0.020
Chlorpyrifosmethyl	10	20	2	2	0.1		0.010
Etrimfos	5	10	5	1	0.1		0.003
Fenitrothion	10	20	5	1	1.0		0.005
Methacrifos	10	20	10	2		5	0.003
Pirimiphos-methyl	10	20	5	2	1.0		0.010
Dichlorvos	2		0.5	0.5			0.004
Carbaryl		20	2	0.2		1	0.010
Pyrethrins	3					1	0.040
Deltamethrin	1	5	1		0.1	1	0.010
Bioresmethrin	1	5	1	1			0.030
Phenothrin	2	5	2	1			0.070
Permethrin	2	5	2	0.5		0.1	0.050
Fenvalerate	2	5	2	0.2			0.020
Piperonyl butoxide	20					8	0.030

Fumigants	Raw cereals	Milled cereals	Cooked cereals
Methyl bromide	5	1	0.01
Inorganic bromide	50	50	-
Phosphine	0.1	0.01	-

* In some instances the FAO/WHO recommendation applies specifically to a particular grain but, in general, it is reasonable to consider the MRL as potentially applicable to most whole cereal grains (specifically excepting milled rice).

** Acceptable daily intake (ADI) of a chemical is the daily intake which, during an entire lifetime, appears to be without appreciable risk on the basis of known facts.

Adapted from Pest Control for Food Security, *Plant Production and Protection Paper 63* (Prepared for FAO by ODNRI), FAO, Rome (1985) and the World Food Programme Storage Manual (1992) (Prepared for FAO by ODNRI).

A recent development affecting the distribution and use of pesticides has been the publication, by FAO, of a Code of Conduct (Anon., 1990). The purpose is to indicate responsibilities and establish voluntary standards of conduct for all public and private bodies engaged in or affecting pesticide distribution or pesticide use. It is particularly directed to countries where national regulatory legislation is lacking or inadequate. It draws attention to a comprehensive series of guidelines, also published by FAO, on regulatory practices, packaging and storage of pesticides, labelling of containers, disposal of waste pesticides and their containers, and other pertinent matters including especially the Prior Informed Consent (PIC) Procedure. This aims to protect the right of countries importing pesticides to be made fully aware of bans or restrictions placed on particular pesticides, elsewhere, so that informed decisions may be made on whether or not further importations of such pesticides should be permitted. Insecticides covered by the PIC procedure include, for example, DDT and lindane which have been mentioned already as compounds which remain in use in several developing countries although banned or severely restricted elsewhere.

Current usages for stored-grains pesticides, including fumigants and contact insecticides, constraints on their use and the ways in which chemical pest control may be integrated into storage systems are subjects which have received much attention. The following account may be usefully augmented by reference to various publications including, for example, Champ and Highley (Eds.) 1985.

The use of fumigants

Fumigants are toxic gases used to disinfest a commodity in an enclosure which, ideally, is completely gastight. Fumigation enclosures should certainly be sufficiently gastight for the gas to penetrate and remain in the commodity for long enough to kill all stages of the insects present in or amongst the grains. A gas or vapour that does not have the ability to penetrate the grain is not, strictly speaking, a true fumigant.

The purpose of a fumigation is thus to obtain a more-or-less immediate disinfestation of the commodity and the space enclosing it. Fumigation is the only chemical treatment that can achieve this effect and this relative immediacy of disinfestation, together with its completeness if done properly, are the main advantages of this particular chemical control technique. Its main disadvantages are that the treatment confers no residual protection against reinfestation, once the commodity is again exposed, and the fact that the most effective fumigants are all highly toxic to humans and other non-target organisms. The precautions required to ensure the safe use of fumigants are, necessarily, much more stringent than those required to ensure the safe use of most other insecticides.

The list of fumigants in Table 8.6 excludes those that are no longer widely approved for use on stored grain due to restrictions placed upon their use in some countries. Examples are carbon tetrachloride and ethylene dibromide, both of which are low-volatility fumigants with recently identified chronic user hazards. Another low-volatility halogenated hydrocarbon, ethylene dichloride, is not so clearly implicated but is less commonly available than it was formerly. Methyl bromide and phosphine are now the only fumigants commonly in use on a world-wide scale. The advantages and disadvantages of these two fumigants are summarised in Table 8.7. In addition, it should be noted that both phosphine and methyl bromide are currently regarded as gases with potential negative impact on the atmospheric

environment. Constraints on their use are likely to increase and requirements for careful, responsible use, with more regular monitoring of application rates, are likely to be more strictly enforced.

Table 8.7. Phosphine and methyl bromide as fumigants: advantages (**highlighted**) and disadvantages.

Phosphine	Methyl bromide
Easy to transport	Refillable cylinders are expensive to transport
Easy to apply	Difficult to apply, requiring special equipment and skill
Good penetration and distribution	Distribution rather poor
Taint, residues and loss of viability in treated seeds are generally negligible	Sorption occurs and may cause taint, bromide residues and loss of viability in treated seeds
Slow acting, particularly at low temperatures and humidities*	**Rapidly toxie and widely effective even at lower temperatures**
Flammable: spontaneously explosive ignition can occur in some circumstances	**Non-flammable**
High acute mammalian toxicity but **low chronic toxicity**	Dangerous acute and chronic poison with delayed symptoms
Fairly easy to detect	**Very easy to detect**
Rapidly lost by leakage unless fumigation space is well sealed and gas tight soon after application	Needs very good seaing before application

* Not recommended for use at temperatures below 12°C.

Source: Adapted from Pest Control for Food Security, FAO *Plant Production and Protection Paper 63* (Prepared for FAO by ODNRI), FAO, Rome (1985).

The desirable properties of a grain fumigant, notably efficient penetration of the commodity, toxicity to target insects and lack of harmful residues, make it unlikely that new chemical compounds will become available as fumigants (Taylor, 1991). Carbon dioxide can be used as a conventional fumigant but low toxicity to insects and the consequent high degree of gastightness necessary for effective insect control makes it unlikely that this gas will find widespread use except in controlled atmosphere (CA) storage systems.

Detailed information on the properties and use of phosphine and methyl bromide as grain fumigants, including application procedures for fumigations in various types of fumigation chamber or under gas-proof sheets, is included in a separate FAO publication (Bond, 1984) and is not reproduced here. General guidance on dosage rates, however, is given in Tables 8.8a and 8.8b. It should be noted that, for phosphine, there are considerable differences in tolerance amongst the various insect pests of stored grain. The data in Table 8.8a are intended to illustrate this rather than to indicate practical dosages. A general dosage recommendation is given beneath the table. For methyl bromide, differences in the amount of gas sorbed by particular commodities are generally more important and these are taken into account by the schedules presented in Table 8.8b.

Table 8.8a. Average concentrations of phosphine (mg/l) required to give 100 per cent mortality of all developmental stages of insects under experimental conditions.

Temperature	15°C		25°C			30°C	
Duration of exposure (days)	4	8	2	4	7	2	7
Sitophilus spp.		>1.50	>3.0	1.65	0.32	>0.36	0.05
Rhyzopertha dominica			1.6	0.18	0.02		
Lasioderma serricorne	0.36	0.04	1.6	0.32	0.15	>0.36	0.17
Trogoderma granarium	>1.30	0.77	0.8	0.32	0.08	>0.36	0.17
Acanthoscelides obtectus			3.0	0.32	0.15	0.36	0.09
Caryedon serratus				0.32	0.20	0.36	0.05
Ephestia elutella		>1.50	3.0	0.09	0.05	0.15	0.05
Ephestia cautella	>1.30	0.77	1.6	0.03	0.02	0.05	
Ephestia kuehniella	>1.30	0.77	1.6	0.03	0.02	0.05	
Plodia interpunctella	1.30	0.18	1.6	0.03	0.02	0.05	
Tribolium castaneum	0.03		0.16	0.08	0.04	0.02	
Oryzaephilus surinamensis	0.03		0.04			0.05	
Cryptolestes pusillus			0.16	0.08	0.01	0.36	0.05
Cryptolestes ferrugineus				>0.08	0.04		
Ptinus ocellus (=P.tectus)	1.30	0.18	0.40	0.08	0.04		

Note: For practical fumigations, which must allow for some loss of fumigant during the exposure period and for diurnal temperature fluctuations, **the recommended treatment for effective control of all species, including the most tolerant, is $2g/m^3$ (2mg/l) for not less than 5 days at 20°C or above.** Recent work (Taylor and Harris, 1989) has shown that this is sufficient also for the control of the Larger Grain Borer *Prostephanus truncatus* which was not amongst the insects previously studied (Table 8.8a above).

Source: Ministry of Agriculture, Fisheries and Food, Agricultural Science Service, Slough Laboratory, Slough, UK.
In: Pest Control for Food Security, *FAO Plant Production and Protection Paper 63* (Prepared for FAO by ODNRI), FAO, Rome (1985).

Table 8.8b. Dosage schedules for fumigation with methyl bromide where the enclosed volume is filled, e.g. stacks under gas-tight sheets.

	Stowage factor (m^3/tonne)	Dosage (g/tonne)		Dosage (g/m^3)		Exposure (hours)
Commodity temperature		10-20°C	>20°C	10-20°C	>20°C	
Rice (milled) & peas	1.4	36	23	25	16	24
Barley	1.7	40	26	23	16	24
Beans	1.8	42	27	23	15	24
Paddy rice	1.9	44	28	23	15	24
Wheat, lentils	1.4	51	34	36	24	24
Maize	1.6	54	36	34	23	24
Sorghum & millets	1.4	81	54	58	39	24
Empty sacks	1.4	81	54	58	39	48
Flour	1.5	82	55	55	36	48
Pollard & bran	1.8	87	58	48	32	48
Groundnut kernels	1.9	88	59	46	31	48
Groundnuts in shell	3.1	106	71	34	23	48

Notes:

The dosage rate per tonne can be read directly from the table according to the commodity.

Recommended dosages are also given as g/m^3 for situations where the volume, but not the weight, of the commodity is known. The volume dosages have been obtained by dividing the dosage per tonne by the stowage factor. These dosages are alternatives and should not be added together.

Where *Trogoderma* spp. are present, dosage should be increased by 50 percent.

If a 48hr exposure period is reduced to 24 hours the dosage rate should be increased by 50 per cent. If a 24hr exposure period is increased to 48 hours the dosage rate should be reduced by not more than 30 per cent.

Where stacks of less than $30m^3$ (approximately 20 tonnes) are treated under sheets, dosages should be calculated as if the volume were $30m^3$ (20 tonnes).

Adapted from: Pest Control for Food Security, *FAO Plant Production and Protection Paper 63* (Prepared for FAO by ODNRI), FAO, Rome (1985)

Phosphine, because of its availability in solid formulations of metal phosphides which are relatively easy to apply, compared with the pressurised gas fumigant methyl bromide, has become the most popular and widely used fumigant in most tropical countries. Methyl bromide, which is in some ways more versatile, retains its place as the fumigant of choice

wherever circumstances do not easily accommodate the protracted fumigation period, of several days duration, that is required for the effective use of phosphine.

The further prolongation of recommended exposure periods for phosphine, beyond the three day minimum that was formerly recommended for hot climates, followed from extensive investigations into the susceptibility of the developmental stages of storage beetles (Hole, *et al.* 1976). The pupal stage of grain weevils was found to be remarkably tolerant but other life stages were shown to be sufficiently susceptible to permit effective use of phosphine if the minimum exposure period were extended to 4 days, at favourable temperatures, to allow the tolerant pupae to pass into the more susceptible adult stage.

The growing frequency of resistance to phosphine in storage insects constitutes a problem, previously discussed, but does not generally invalidate the use of this fumigant which can still be expected to provide effective control of the major pest species when treatments are carried out using proven techniques (Taylor, 1991). Problems may arise where control measures against psocids are warranted. Considerable tolerance to phosphine, in all the life stages but especially the egg, has been demonstrated in the common species *Liposcelis entomophilus* (V. Pike, personal communication). The same investigator has shown that the currently available alternative fumigant, methyl bromide, should prove effective at normal dosage rates whereas effective phosphine treatment would require an extension of the exposure period beyond the normally practicable limits for sheeted-stack fumigation. Tolerance to phosphine in the egg stage has also been observed in other insects (Hole *et al.*, 1976; Bell, 1976) but this does not generally persist throughout egg development as it appears to do in *L. entomophilus*. It is this persistent tolerance, throughout a 6-9 day developmental period (at 27°C), which makes phosphine unreliable for psocid control. It may also explain the rapid and spectacular resurgence of psocid infestation, following phosphine fumigation and the elimination of susceptible predators and competitor species, in those grain storage situations where this phenomenon has been observed.

Practical constraints on the use of fumigants to treat stored grain include consideration of the chemical residues which they may leave in the treated grain and the effects which such residues, or the treatment itself, may have on grain quality. For seed grain this includes germinability and seedling viability. In this regard phosphine has considerable advantages and is certainly to be preferred over methyl bromide for seed treatment. It is also less commonly associated with problems due to persistent sorbed chemical residues. Problems can arise from the visible residues of the metal hydroxide which remain after the decomposition of tablet or pellet formulations. Moreover, these usually contain some undecomposed phosphide, which can also be found in spent satchets and other application packets. However, the hydroxide material itself is not harmful and the risk posed by undecomposed phosphide can be sufficiently minimised if recommended procedures are followed.

The available advisory literature on fumigation procedures relates mainly to relatively large-scale applications in warehouses and other storage complexes. Possible small-scale applications in tropical developing countries, at farm level or by urban traders, should not be disregarded. Such operations were, in the past, largely limited to the occasional use of low-volatility halogenated hydrocarbons: notably various mixtures of ethylene dichloride with carbon tetrachloride. Such formulations may still be available in some countries but their

use is now generally discouraged because of recently identified long-term user-hazards. Methyl bromide and most other high-volatility fumigants are generally precluded by the much greater acute toxicity hazards and by the recognised need for special equipment and training for users. The advent of phosphine, however, increased the likelihood that fumigation treatments would be attempted by untrained people. The relative ease of handling the solid formulations of this fumigant, especially the familiar tablets and pellets, greatly facilitates their retail distribution, sometimes without the manufacturer's protective packaging, in any country where effective curbs on such distribution are not in place. Extension workers as well as opportunistic salesmen are sometimes at fault in this regard and, in consequence, phosphine treatments of small farm-level stocks of grain, or of larger quantities in traders' stores, may be carried out ineffectively and may in some instances be a serious hazard to the user or other people. Inefficient use of phosphine, as has been mentioned already, will also exacerbate the insect resistance problem. Proposed efforts to monitor phosphine use and to promote effective techniques should be extended to include small-scale applications and should give full attention to associated hazards. Where necessary, tighter controls on the sale and use of phosphine should be introduced and applied.

Developments in fumigant application techniques

(i) Store fumigation

The concept of fumigating the free space and entire contents of a store, rather than individual stacks of bagged grain, is not new and has been practised regularly for many years, particularly in South Asia. This method of disinfestation has the potential advantage of controlling insects on the walls, floors and inner roofing surfaces, as well as in the grain, thus greatly reducing the immediate re-infestation pressure on the store contents.

Unfortunately, most whole store fumigation in the past has been carried out in buildings that were not designed specifically for this method of disinfestation. As a consequence, most were not capable of retaining fumigant gas sufficiently well to provide complete control of insects. There seems little doubt that whole store fumigation has encouraged the development of insects that are resistant to phosphine.

Recent investigational programmes have demonstrated that purpose-built storage buildings (Bisbrown, 1992) can serve effectively as fumigation chambers. In Sahelian West Africa, for example Senegal (Hayward, 1981), such stores already exist. However, there is little evidence that they are regularly used for that purpose.

Where existing storage buildings can be sealed to render them reasonably gas-tight, investigations have shown that effective fumigation can be achieved using a method of phased dosing with aluminium phosphide. The method involves application of fumigant in two portions, the second of these 24 or 48 hours after the initial application. Using this technique it is possible to prolong the period during which insects are exposed to a lethal concentration of fumigant, even in buildings in which some leakage of gas is taking place (Friendship *et al.*, 1986).

(ii) Sheeted stack fumigation

In most developing countries, the commonest method of fumigating stored commodities is with bag stacks under sheets. The technology involved is relatively basic and good standard recommendations are available, including detailed advice on choosing suitable sheets (Friendship, 1989). Nevertheless, many fumigations of this type are carried out unsatisfactorily. Common reasons for treatment failure are the use of torn or perforated fumigation sheets, which allow fumigant to escape, or poor sealing of sheets at ground level which also allows excessive leakage. The most common method of sealing sheets at ground level is by means of tubular sandbags ('sandsnakes') which hold down the sheet in contact with the floor. Frequently, insuffìcent of these are provided to permit satisfactory sealing, or the sandsnakes are too small or too lightweight to effect a gas-tight seal. Proper sealing of sheets requires sandsnakes to overlap continuously around a stack, with at least two sandsnakes over the folded sheet corners. Latest experimentation suggests that for effective sealing of heavy-duty (and less flexible) sheets, such as those of laminated PVC, larger and heavier sandsnakes are necessary than those commonly used. The width of tubing used for the larger sandsnakes should be of the order of 150 to 200 mm. These, when filled, should provide a contact width on the floor of at least 100 mm. A disadvantage of this type of sandsnake is the increased weight, which is an important consideration for pest control teams with frequent operations or much travelling to do. It is therefore advisable to ensure that the heavier type of sandsnake is not too long, and is fabricated from strong material such as lightweight canvas. Where possible, sandsnakes should be provided for each individual store or store complex to avoid the need for further transportation.

(iii) Circulatory systems for phosphine

A recently introduced and patented technique known as 'Phyto-Explo Fumigation' enables bulk grain to be effectively treated in deep structures using phosphine. A shaft is driven into the grain, using compressed air, and is connected to a piping system which allows air circulation within the grain by means of a small pump. Fumigant is evolved from a phosphide formulation introduced into the headspace above the grain and gas is drawn down into the grain by the circulatory action of the pumping system. This technique permits effective distribution of fumigant in deep silos and in ships holds, rendering disinfestation possible without transferring the grain. The same technique can be used with methyl bromide enabling rapid treatment of silos not provided with a permanent circulatory system.

The use of contact insecticides

Currently acceptable compounds, and recommended rates for their application as dust formulations admixed with cereals or as liquid surface treatments, are given in Table 8.9. Compounds used for space treatments, and their recommended application rates, are given in Table 8.10. These two tables (and Tables 8.5 - 8.8) are reproduced from FAO Plant Production and Protection Paper 63 (Anon., 1985), a manual of pest control for food security reserve grain stocks prepared for FAO by the former Storage Department of TDRI (now NRI). This contains detailed information on application procedures and equipment for fumigants and contact insecticides.

Most reputable insecticide manufacturers also provide useful literature on application rates for their own products together with appropriate safety precautions which should be followed. Some also indicate suitable application equipment and there are many other publications, with or without commercial bias, which give comprehensive guidance on the various spray-pumps, mistblowers and fog generators that are available. The choice of a particular piece of equipment is generally less important than the care given to its use and maintenance. The best advice to give here is that the choice should be made, on the basis of information obtainable from accessible sources, with particular regard to cost, availability of spare parts, the user's own assessment of suitability for the purpose and the apparent robustness of the equipment.

The focus of attention in this bulletin is upon the differences between the various types of insect control treatments, i.e. the application techniques, with regard to pest control objectives and the constraints which limit effectiveness in particular circumstances.

Table 8.9. Recommended insecticide application rates.

Insecticide	Dust admixture with cereals (ppm)	Surface treatments (g/m^2)	
		Walls	Bags
Malathion	8-12	1-2	1-2
Pirimiphos methyl	4-10	0.5	0.5
Fenitrothion	4-12	0.5	0.5-1
Chlorpyrifos methyl	4-10	0.5-1	0.5-1
Dichlorvos	2-20*	0.5	
Methacrifos	5-15	0.2	0.4*
Lindane	-	0.5	
Pyrethrin/piperonyl butoxide (1:5)	3	-	0.1
Bioresmethrin (resmethrin)	2	-	
Phenothrin	5	-	
Permethrin	-	0.05-0.1	0.05-0.1
Carbaryl	5-10	1-2	-
Bendiocarb	-	0.1-0.2	-
Dioxacarb	-	0.4-0.8	-
Propoxur	-	0.5	-

Notes: * Short persistence. '-' The insecticide is not normally used in that type of treatment.

Source: Pest Control for Food Security *Plant Production and Protection Paper 63* (Prepared for FAO by ODNRI) FAO, Rome (1985).

(i) Grain admixture treatments

Admixture treatments depend upon reasonably uniform application of a suitable contact insecticide, or in some cases a mixture of insecticides, at an acceptable dosage level. Table 8.9 gives application rates in parts per million (ppm) of the *active ingredient* for a range of commonly used insecticides applied as dusts (dusting powders) on grain. Such formulations are generally recommended for small-scale treatments because dusting powders are fairly easily supplied, ready for use, in suitable small packs and are more easily applied. Liquid formulations can also be used, if suitable application equipment is available, and these are generally preferred for large-scale treatments. This is especially true in commercial grain storage, mainly because the admixture of dusts with grain alters the bulk density and may affect grading standards but also because spray applications are more easily automated and incorporated into grain conveying systems.

In either case the application rates specified in Table 8.9 apply and it is most important to understand that these rates are for the active ingredient (a.i.). It may help to think of these as *a.i. dosage rates* to distinguish them from the *formulation application rates*. These latter are more or less standard, at 50g or 100g of dusting powder per 100kg of grain or 1-2 litres of the dilute spray-mix per tonne of grain. For liquid treatments the most convenient carrier is water and the application rate is designed to allow effective treatment with minimum added water. A simple calculation shows that for grain treated at 1 litre/tonne with a water-based spray the moisture is increased by approximately 0.1%. The calculation of the required concentration of active ingredient in the spray-mix or dusting powder, to give the recommended dosage rate in ppm, weight-for-weight on the grain, is also quite straightforward. The simplest possible example is that an *a.i.* dosage of 10ppm on grain will require a 2% dusting powder applied at 50g/100kg grain or a 1% powder applied at 100g/100kg. Likewise, it will require an approximate 1% spray-mix for an application rate of 1 litre/ tonne.

The advantages of insecticide admixture treatments are that they are generally inexpensive and a single application of an effective insecticide, correctly formulated, will give control of existing insect infestation (including, eventually, any insect stages within the kernels) and will protect the grain against reinfestation for a substantial period. The duration of protection varies considerably between different insecticides and, more importantly, between different climatic conditions. In the tropics, relatively high grain temperatures may reduce performance to some extent, although the preferred insecticides will generally give good results for several months. High moisture content (above the recommended 'safe storage' level) in the treated grain will more seriously impair the performance of some insecticides: notably malathion and fenitrothion. However, it is usually possible, by good storage management, to delay the treatment of grain until it is sufficiently dry and this should be the objective (Daglish and Bengston, 1991).

Disadvantages of admixture treatments include the effect of admixed powders upon the bulk density of the grain, but in many situations this is unimportant, or the risk of over-wetting the grain if water-based sprays are used carelessly or in unreliably automated spray-rigs. However, the practical problems of ensuring the availability of stable insecticide formulations, especially with ready-to-use dusting powders, have proved to be the major constraint on successful widespread use of the technique. Malathion in particular is very

prone to instability if formulated as a dilute dusting powder (usually at 2% w/w) on an unsuitable carrier. Many of the more recently introduced insecticides, including for example pirimiphos-methyl ("Actellic") and the synthetic pyrethroids, appear less prone to this problem. However, effective quality control on dilute dusting powders, which are mostly formulated locally to avoid heavy transport costs, is essential to the success of insecticide admixture treatments recommended for use at the small farm level in developing countries. Formulations should be monitored for stability and to ensure that the nominal concentrations are initially correct. Distribution channels should also be controlled to ensure that retail packets are withdrawn before sale if they have been in stock for longer than the predicted shelf-life.

(ii) Insecticide deposits on bulk grain surfaces and bagstacks

Spraying the surface of a bulk of uninfested grain, in a bin or in flat bulk storage, can give quite good protection against reinfestation for a limited period, depending on the persistance of the insecticide used. Application rates would be similar to those indicated for other surface treatments in Table 8.9. For sustained protection the treatment would have to be repeated rather more frequently than is usually recommended. The decay of insecticidal effectiveness on exposed surfaces is generally faster than in a bulk treated by admixture and re-spraying at intervals of more than 1-2 weeks is likely to allow a limited build-up of infestation which, once established in grain below the surface, will be largely unaffected by retreatment. In practice, control of warehouse moths is often quite well achieved but control of beetle pests is generally less effective. Quite good control of the grain moth, *S. cerealella*, is also likely since this insect is unable to penetrate far below the surface of a grain bulk.

An alternative treatment, for the same purposes, would be the use of a dusting powder applied to the surface and raked-in to a depth of 10-20cm. The application rate should be as indicated in Table 8.9, based on the estimated grain weight in the treated surface layer. Insecticidal sprays and dusting powders applied as surface treatments to protect fumigated bagstacks against reinfestation are also of limited effectiveness. Early work showed that layer-by-layer spray treatments, applied during the building of a bagstack and immediately prior to fumigation, could be reasonably effective. For example, malathion, applied at about $1g/m^2$ in a water dispersible powder formulation, gave complete protection against *T. castaneum*, in tropical conditions, for 1-2 weeks and a useful degree of control for 4-6 weeks (McFarlane, 1961). Respraying of exposed surfaces, at monthly intervals, was suggested for longer storage periods. However, in practice, the initial layer-by-layer treatment is rarely if ever used and bagstack spray treatments are generally limited to the exposed surfaces with re-application at monthly intervals or even less frequently. A broad concensus of opinion, based on observations in practical storage situations, regards these treatments as generally ineffective in tropical climates. Where they are used, even on a regular basis, the need for periodic refumigation to combat resurgent infestation is not avoided. There is considerable evidence that this resurgence is due to reinfestation at the stack surfaces although faulty initial fumigation may sometimes be partly to blame.

(iii) Insecticide deposits on the fabric of grain stores

The notional contribution made by fabric treatments to the sustained control of insect infestation in warehouses has rarely, if ever, been confirmed in practice. On the other hand, it is considered likely that they do contribute substantially to the build-up of insect resistance to pesticides.

Recent trials in grain storage warehouses in Java (Hodges *et al.*, 1992) found no substantially significant differences in the resurgence of pest populations, following the fumigation of all bagstacks and an initial spray treatment of the warehouse fabric using fenitrothion at $1 g/m^2$, between warehouses with routine, monthly respraying of walls, or walls and floors, and those with no respraying treatment.

There can be little doubt that properly applied surface treatments of walls and floors, using a recommended insecticide at the correct application rate (Table 8.9), will kill many, if not all, of the insects exposed to the insecticidal spray or to the residual deposit immediately after the treatment. However, although a persistent insecticidal effect can be found on some surfaces, for many days and even for many weeks, it is inevitably a declining effect. Actual efficacy, in terms of insect control, is unlikely to be very great. As noted by Hodges *et al.* (1992) many of the insects which enter a store in the tropics do so in flight and the proportion of these that will settle upon a sprayed surface for long enough to be killed by the diminishing insecticide deposit can hardly be very great.

The practical value of these treatments may be considerable when they are used as a supplement to physical cleaning, in an unloaded store, to kill insects which may remain on the fabric of the store even after reasonably thorough sweeping. Repetitive use, as an alternative to more effective measures to control infestation in the stored grain, are of little value and may, conversely, have negative effects in the long term by accelerating the development of resistance to the insecticides used.

(iv) Space treatments

This term is used to describe insecticidal treatments, by aerosols or vapours, intended to kill insects exposed to the treatment in the free space of a store or other enclosure to which the treatment is applied. They are thus quite distinct from true fumigations and cannot be expected to disinfest commodities within the enclosure.

Space treatments, to be effective, require reasonably good sealing of the enclosure which should certainly be made windtight. Complete gastightness is not essential.

Most of the insecticidal formulations that have been employed for space treatments leave a small residual deposit upon exposed surfaces and may have a slight persistent insecticidal effect. However, this is generally negligible unless the treatments are applied repetitively and frequently. Space treatments achieve most effect through their direct impact on insects in flight or trapped on exposed surfaces during the treatment. In general, and probably for this reason, they appear to be most effective against warehouse moths and some other insects (such as the beetle *L. serricorne*) that spend little or no time concealed within a commodity bulk or bagstack. For maximum effect, even against these more susceptible species, space

Table 8.10. Application rates for space treatments.

Insecticide	Type of treatment	Recommended application rate (active ingredient)
Dichlorvos*	Single or occasional misting:	35 to 70 mg/m^3
	Weekly or twice-weekly misting:	15 to 23 mg/m^3
	Daily misting:	5 to 10 mg/m^3
	Strip dispenser replaced every 2-3 months:	1 per $30m^3$ space
Pirimiphos methyl (actellic)	Fogging:	50 to 100 mg/m^3
	Misting every 2 weeks:	20 mg/m^3
	Smoke (every few weeks):	35 to 40 mg/m^3
Pyrethrins synergised with piperonyl butoxide (1:)	Occasional misting or fogging:	1.5 to 3 mg/m^3 applied as 1 litre of 0.3% to 1,000 to 3,000 m^3
	Daily application by automatic misting:	1 mg/m^3
	Treatment to obtain a residual deposit:	25-45 mg/m^3 applied as 15 litres of 0.3% to 1,000 m^3
Bioresmethrin or synthetic pyrethroid mixtures	Misting:	0.5 to 1 mg/m^3
Lindane	Smoke for residual protection against beetles:	100 mg/m^3
	Smoke for immediate effect on moths and flies:	25 mg/m^3

* Formulation obtainable as 7% w/v to 100% w/v for direct application without dilution.

Source: Pest Control for Food Security *FAO Plant Production and Protection Paper 63* (Prepared for FAO by ONDRI) FAO, Rome, 1985.

treatments should be applied regularly and frequently: preferably daily at dusk when insects are generally most active in flight.

Aerosols containing pyrethrins, with or without a synergist, applied as thermal 'fogs' or mist-sprays ('cold fogs') were previously the treatment of choice in stored-grain pest control but cheaper alternatives are now more often used. Various synthetic contact insecticides can be used in aerosol formulations and one compound, dichlorvos, can be used effectively as a vapour treatment (McFarlane, 1970; Ashman *et al.*, 1974) in those countries where its use is approved.

Application rates for space treatments are given in Table 8.10. The mention given to lindane and pirimiphos methyl 'smoke' treatments relates to the use of the solid particle aerosols commonly referred to as smoke generators. Lindane 'smokes', in particular, have been shown to have a considerable residual effect, when applied frequently or at the higher dose indicated in Table 8.10, but the use of this insecticide in circumstances where its residues may accumulate in foodstuffs is not acceptable.

Safety precautions

Wherever toxic chemicals are used in pest control the maintenance of safety should have highest priority. This relates to those handling or applying the chemicals and also to those other persons or animals that may be affected, directly or indirectly, by the chemical treatments. FAO guidelines, previously mentioned, on many relevant asects of safety in use are available from that source.

Detailed information on safety procedures in the use of chemical pesticides is contained in other FAO publications; notably Bond (1984) on the use of fumigants and Anon. (1985) on both contact insecticides and fumigants. All those involved, in any way, in the promotion, planning or implementation of chemical control measures should be familiar with the recommended procedures and should ensure that all appropriate precautions are observed in the situations and circumstances for which they have responsibility.

In addition, the specific precautions recommended by pesticide manufacturers for the use of their products, which are or should be clearly drawn to the attention of the user on all product labels, should be observed by the user. Local sales agents should be required to ensure that hazardous materials are not retailed to users who may be unable to read or understand the accompanying information on application rates and safety precautions. The only exception that should be made to this is where another competent agency takes full responsibility for providing the necessary verbal instruction and practical training to potential users.

ALTERNATIVE AND SUPPLEMENTARY CONTROL MEASURES

The currently available options for grain storage and the pest control methods usually associated with each storage technique are reviewed in Table 8.11. In Table 8.12 the pest control methods themselves, including some of the biological techniques referred to only briefly in the previous Table, are reviewed more comprehensively with regard to their principal advantages and disadvantages.

These Tables, together with those presented at the outset of this chapter (Tables 8.1 and 8.2) should make it fairly clear that most insect control techniques are inherently related to certain forms of storage and, moreover, that none of them is perfectly complete and without disadvantages. Chemical control techniques, although discussed separately in this chapter, should also be seen to depend upon good basic storage practice and to be supplementary to the control achieved by other techniques.

Physical measures

The effects of various physical factors upon insect development and control have been discussed already. The particular measures that are important as supplements to other insect control procedures are cleaning and drying. Those which may provide alternatives to other forms of control are cooled grain storage, hermetic storage, thermal disinfestation and, in some circumstances, mechanical disturbance.

The cleaning and drying of grain for storage are essential measures and the techniques are described elsewhere in this bulletin. Practical difficulties in achieving the desired freedom from excess moisture and foreign matter are frequently encountered. There can be no doubt that failures to overcome such difficulties do occur and that these lead to increased insect infestation. The rate of insect development may be somewhat accelerated and, more importantly, the spectrum of infestation will be greatly increased (Table 8.4). Practical recommendations take best account of this when they acknowledge the difficulties that may occur but emphasise the need for cleaning and drying to be done as thoroughly as possible, especially when grain is to be stored for a long period. The longer the expected storage period, the greater the need for efficient cleaning and drying.

Techniques for the storage of damp grain, in hermetic conditions, under controlled atmospheres or with mould-suppressant treatments, have been developed but these are regarded as unsuited to the storage of grain for use as human food (Christensen, 1982). However, the practical value of ventilated cribs for the storage of maize on the cob and other grains on the head or in the pod, when insufficiently dry for sealed storage, should not be overlooked. Advice on optimum design for maize cribs, with particular reference to the humid tropics where the restriction of crib width to facilitate drying is important, is given in FAO Agricultural Services Bulletin No.40 (Anon., 1984).

The development of other temporary storage procedures, especially for underdried rough rice, has received much attention in countries where the introduction of new cultivars has led to massive production increases and, sometimes, to the regular harvesting of grain in wet weather. Limited applications of mould-suppressant chemicals, such as propionic acid, have

Table 8.11. Storage techniques: current options.

Storage container	Associated pest control methods*
Small-scale bulk storage	
Cribs: - in open air:	- 'smoking' over an open fire - admixing a grain protectant
- inside a dwelling place:	- as above
Underground pits:	- self-disinfesting if sufficiently airtight
Small storage bins:	- admixing a grain protectant
Large-scale bulk storage	
Sealed bunkers:	- admixing a grain protectant - disinfesting by fumigation
Unwelded metal bins:	- as above - cooling by aeration
Flexible (collapsible) bins:	- as above
Concrete bins or pits:	- self-disinfesting if sufficiently airtight - admixing a grain protectant - disinfesting by fumigation or controlled atmospheres
Welded steel bins:	- as above
Storage in bags or small containers	
Sealed pots, gourds, etc:	- self-disinfesting if sufficiently airtight, or admixing a protectant
Conventional bags, (stacked or unstacked)	- admixing a grain protectant - fumigating under sheets (with or without protection against reinfestation) - partially self-disinfesting if tightly stacked
Wrapped bags in sealed pits or bunkers:	- self-disinfesting if sufficiently airtight
Insect-proof packages:	- fumigation or irradiation

Note: See also Table 8.12 which includes biological methods with unconfirmed potential.

been found effective and may be acceptable for short holding periods (5-7 days) prior to proper drying (Kamari and Yon, 1980). The use of admixed desiccants, such as common salt (sodium chloride) or wood ash, may also be of limited usefulness.

Aeration and cooling, by natural aeration in small, ventilated stores (e.g. maize cribs), or by forced aeration in larger stores, can significantly retard the development of insect infestation. Where it is possible to reduce the temperature of a grain mass to 17°C or less the infestation will be effectively suppressed although not eliminated. Suppression could be achieved, by selective aeration, in many parts of the tropics where early morning temperatures are of this order. More attention should perhaps be given to this (Gough and McFarlane, 1984; Calderon *et al.*, 1989). The particular importance of maintaining relatively cool storage conditions for seed grain stored in tropical climates is well known (Christensen, 1982). The trade-off between design costs, for improved thermally-insulated storage structures, and the cost of drying the grain to very low moisture-content, to counteract the effect of high temperature, has been analysed by O'Dowd *et al.* (1988).

The principles of hermetic storage are outlined elswhere in this chapter. Small-scale applications in the tropics are not uncommonly reported and attempts have been made to encourage the use of this technique in many parts of the tropics. However, it can only be cost-effective, in practice, where the storage management objectives will accomodate the principle and where suitable containers are available at a reasonable price. It is best regarded as a technique for selective application to particular commodities or to particular stocks clearly identified as reserves for protracted storage. Large-scale applications are likely to be handicapped by the cost of maintaining airtightness in large structures and by the common commercial requirement that grain stocks should be renewed at regular intervals (Hyde *et al.*, 1973). However, considerable interest in the technique remains (Calderon *et al.*, 1989).

Thermal disinfestation techniques include simple exposure to the heat of the sun, a traditional procedure that can achieve disinfestation in thin layers of exposed grain but which may often, in practice, do no more than drive off any adult insects or free-moving larvae. At the other extreme is the sophisticated technique, based on fluid-bed grain drying systems, described by Dermott and Evans (1978). Between these extremes lie opportunities for using solar drying equipment for grain disinfestation (McFarlane, 1989) and the occasional use of conventional hot-air grain dryers for this purpose in the reconditioning of infested grain. All of these techniques need careful management to ensure an effective kill of all stages of the insects in the grain without causing physical (thermal-stress cracking) or physiological (germinability loss) damage to the grain. This can be achieved in the simplest and most sophisticated systems, it is least likely to be achieved by the use of conventional hot-air dryers. Thermal disinfestation (like fumigation) provides no ongoing protection against re-infestation and, moreover, if heated grain is put into storage without sufficient cooling any subsequent infestation may develop very rapidly.

Mechanical disinfestation techniques also show a range of refinement from the simple turning of grain through bulk-handling systems (Joffe, 1963) to the use of sophisticated percussion machines (entoleters) in flour mills. As with thermal disinfestation, the treatment provides no ongoing protection and may cause physical damage to the grain which, if it is returned to storage, may therefore be made susceptible to infestation by a greater range of insect species.

Table 8.12. Pest control techniques: current options.

Control method and major uses	Advantages	Disadvantages
*Fumigations** with penetrating gas; for disinfestation in storage or prior to export.	Pest mortality is almost immediate and can be total.	No residual protection. No control of pests outside the enclosure.
*Space treatments** with contact insecticide: to control flying insects especially moths.	Spectacular effects. Can be useful as an adjunct to fumigation.	Only a small part of the total population affected.
*Residual treatments** with contact insecticide: for long-term protection of food stocks.	Effective protection for some time after treatment especially with insecticide admixture; less effective with surface treatments.	Effectiveness varies with circumstances. Highly dependent upon the availability of suitable, high quality formulations.
Heat treatment for disinfestation before storage or export.	Pest mortality is almost immediate and can be total.	Relatively advanced technology needed to ensure success and to avoid adverse effects. Solar dryers may offer a cheaper alternative.
Cooling for sustained pest control during storage.	Highly effective and economic in some situations.	Not usually feasible in the low-altitude tropics without expensive equipment.
Entoleters to disinfest flour before storage or despatch.	Convenient in modern processing systems.	Not practical in all circumstances.
Physical barriers to protect uninfested or disinfested goods in storage and transport.	Can be cheap and very effective if well designed and managed.	Enclosed goods may need to be drier than usual or specially aerated if the barriers impede moisture vapour movements.
Trapping to control rodents or monitor pest populations.	Can be inexpensive, simple and effective.	Ineffective for control unless combined with other methods.
Controlled atmospheres for long-term storage.	Potentially highly effective.	Suitable storage structures are usually expensive.
Pheromones to monitor pest populations or reduce them by behavioural disruption.	Very effective for monitoring low-density populations.	Currently available for relatively few pests. Rather expensive.
Food attractants to monitor or reduce pest populations.	Simple and effective for population monitoring.	Ineffective for control unless combined with other methods.
Growth regulators: for long-term control by the reduction of population growth.	No proven advantages in storage control.	Currently experimental and few available for use.
Pest pathogens to eliminate or reduce populations.	Relatively pest specific.	Pests may show high natural tolerance.
Predators and parasites to reduce populations.	Natural occurrence.	Ineffective until pest populations are well established.
Resistant varieties to reduce the rate of population growth.	Effective throughout the storage period.	May conflict with other plant-breeding objectives.
Sterile insects to reduce population growth rates.	No proven advantages in storage pest control.	Technique requires sophisticated equipment and management.

* All chemical methods are relatively cheap and can be highly effective, but have the disadvantage of eventually causing pest resistance.

Source: Adapted from Dobie (1984)

Traditional grain protectants

The occasional use of abrasive mineral dusts, natural desiccants like wood ash and various plant materials with repellent or insecticidal properties is well known and documented (Golob and Webley, 1980). Recent interest in such materials, intensified by a common concern to reduce, if possible, the general dependence upon synthetic pesticides by promoting the use of alternative materials, has produced a flood of information on experiments that have tested many plant materials. Regrettably, much of the published information is of limited value because practical aspects, including availability and acceptability for use as food grain protectants, are generally overlooked. However, a new bibliographic database on this research has been produced (Rees, Dales and Golob, 1992) which sorts more than 1000 references to work, mostly published since 1980, according to the materials used and the insect species against which they have been tested. The authors point out that the majority of papers in the database describe laboratory experiments or small-scale trials at research stations and that the conclusions drawn by the authors therefore have little significance for practical application. They indicate the need for further work that focusses attention on practicalities. This should, incidentally, reduce the currently over-extended list of candidate materials to more realistic proportions.

It is fair and useful to note here that there have been a few exceptional papers on work in this area. Some recent work in Colombia (Baier and Webster, 1992), for example, included practical on-farm trials which assessed a vegetable oil, kitchen ash and black pepper as protectants for stored beans and included realistic evaluations of economic effectiveness and acceptability. The latter aspect included effects on germination, palatability and cooking time, which were found to be insignificant. All three treatments gave effective protection against *A. obtectus* for several months, taking 4% grain damage as the economic damage level.

Other workers have identified various commonly available cooking oils, notably palm oil but also groundnut oil and coconut oil, as being particularly effective (and used in some countries) for the protection of pulses against bruchid beetles. The oil obtainable from the seeds of the widely-grown neem tree (*Azadirachta indica*) has also been found effective but comprehensive evaluations of its economic acceptability are less easily identifiable. Makanjuola (1989) gives a good account of laboratory investigations and field trials in Nigeria that tested other materials from the neem tree, including water-based leaf extracts, for the protection of cowpeas and maize. The results showed good protection of cowpeas (against *C. maculatus*) for five months but only moderate protection of maize (against *S. zeamais*) and found that seed extracts were more effective than leaf extracts.

Modern biological methods

Irradiation techniques and controlled atmosphere storage are included here, although they may also be regarded respectively as physical and chemical techniques, because their use depends upon radical interference with biological systems or processes.

Watters (1972) and Banks (1976) give useful reviews of the possible applications of various irradiation techniques. There has been much subsequent research, especially to determine suitable dosage rates and operational procedures, with regard to safety as well as efficacy,

but the use of irradiation as a direct control measure remains limited by basic problems of capital cost, running costs and other aspects of practical feasibility. The method shares with fumigation and thermal disinfestation the obvious disadvantage that it confers no protection against reinfestation. Insect resistant packaging of grain or grain products, immediately prior to irradiation, would seem the most logical adjunct in countries where socio-economic circumstances favour the adoption of this sophisticated and relatively expensive control technique. The indirect applications of irradiation, to achieve the suppression of pest populations through the release of sterilised males of the pest species, appear unlikely to prove economically attractive for the widespread control of grain storage insects.

Controlled atmosphere (CA) storage has become an important addition to the available options for stored-grain pest control. Extensive information on CA storage is now available and recent symposia on this research area have presented several comprehensive compilations, the most recent by Champ, Highley and Banks (Ed.) 1989. The present position and future prospects are usefully reviewed by Banks, Annis and Rigby (1990).

Conventional biological control techniques for possible application in stored-grain pest control, including control by the use of predators, parasites, insect diseases and sterile males, the use of pheromones for pest monitoring, mating disruption or enhanced mass trapping, and the use of resistant crop varieties, are summarised in McFarlane (1989), based on papers by Dobie (1984), Haines (1984) and Hodges (1984). There are published reports of the successful practical application of a number of these techniques, notably in the USA (McGaughey, 1978; Arbogast and Mullen, 1990; Brower and Mullen, 1990; Brower and Press, 1990), but the area of most interest for application in tropical countries is the use of crop varieties with resistance to storage insects as well as preharvest pests. The conceptual impact of some of these biological control techniques is indicated in Figure 8.4. It should be noted that control by the use of a resistant variety will generally retard the increase of infestation and grain damage, thereby prolonging the period in which damage remains relatively low, while control by predators or parasites can be expected to suppress the pest population and the consequent grain damage but is unlikely to restrict insect numbers or grain damage to a low level.

Current possibilities for integrated pest management

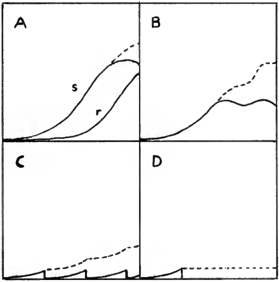
(i) Farm level improvements

As suggested by Dobie (1984) and many other authors the development and use of improved grain cultivars, with resistance to storage insects as well as to preharvest pests, could provide the key element in IPM for stored grains. This would be of particular importance for loss reduction at farm level because, if the improved cultivars were both agronomically suitable and acceptable in all other respects to farm-level users, the adoption of this IPM strategy by farmers should be quite straightforward and would require no change in their traditional approach to grain storage. It would permit the renewed realisation of traditional concepts of safe storage, for a substantial period, by good husbandry alone (Figure 8.4, diagram A). It must be understood that this would not, in most circumstances, reduce on-farm storage losses to less than the customary level generally accepted by farmers storing their own preferred varieties. However, it would reverse the trend towards increased losses which has been observed in those areas where farmers have been encouraged to plant high-yielding

varieties which, typically, are more susceptible to damage by storage insects. Moreover, there should be a net gain provided that improved resistance to storage insects can be coupled successfully with high yield characteristics.

Tactical opportunities for supplementary improvements in grain storage by small-holder farmers are indicated and discussed by Golob (1984) with particular reference to maize grain but considerable relevance to most other grains. They include realistic modifications to traditional storage structures to enhance their performance or to adapt performance to seasonal climatic change. The relative efficacies of various grain protectants, including some of the common traditional materials, are also considered. It is clear that several of these do have some value as a means of further extending the safe storage period but it remains true that reliable formulations of suitable contact insecticides, where these are available to the farmer at a reasonable price, are likely to prove more cost-effective so long as they are properly applied and judiciously recommended. Recommendations for widespread use, without regard to the particular storage objectives of individual farmers, are unlikely to be generally adopted.

Figure 8.4. Pest population growth (solid line) and increase of grain damage (solid/broken line) as affected by different pest management regimes.



A
Retardation of population growth and grain damage by storing a resistant grain variety (r), compared with a more susceptible variety (s).

B
Control by natural enemies.

C
Control by repetitive disinfestation (eg fumigation) without effective prevention of reinfestation.

D
Control by disinfestation with sustained protection.

A need for improved grain stores, modelled on larger-scale bulk storage bins suited to more sophisticated management, is a popular idea that should be treated with considerable caution. There are examples of such developments that have proved successful but a great many more have failed because the real needs and management capabilities of small-scale farmers have not been perceived.

(ii) Improvements in large-scale storage

The main technical options for insect control in large-scale storage, which generally occurs in developing countries at the main depot level or in large grain mills, are summarised in Table 8.2 and have been discussed elsewhere in this chapter. Table 8.2 indicates those techniques which require additional measures for sustained control and those which provide, in the technique itself, this essential element. Measures intended to prevent re-infestation that are of doubtful effectiveness, for reasons already discussed, are pointed out as are those techniques which are likely to require substantial management inputs to ensure success. Bulk storage, which can reduce pest problems or facilitate pest control, should also be considered but should not be regarded as a panacea. The advantages and disadvantages of bulk storage, with particular reference to its use in the humid tropics, are discussed in Champ and Highley (Eds.) 1988.

The choice amongst the technical options to develop cost-effective packages of measures for well-integrated pest control cannot be made without reference to particular situations. As has been previously stressed, it is the storage management objectives, together with the technical and financial constraints, that must be identified and analysed in each case. However, it is of interest that recent decades have seen a marked swing towards the use of physical barriers against re-infestation in combination with improved conventional fumigation or the introduction of controlled atmosphere storage techniques. Notable developments in this direction have been for milled rice storage in China (and in S.E.Asia; Annis *et al.*, 1984), but this approach has considerable technical merit and is potentially of more general application.

The attainment of fully integrated pest management in large-scale storage will depend largely upon the development and adoption of improved pest-monitoring procedures, with increased capability for measuring pest population levels as a parameter of grain damage and quality loss, so as to ensure as far as possible the most cost-effective timing of pest control actions. Here again, in developing countries, recent advances in this direction have been particularly concerned with milled rice storage (Haines *et al.*, 1990).

Increased attention to the monitoring of re-infestation pressure is noted by Desmarchelier (1977) as a requirement for the more cost-effective use of admixed insecticidal protectants. It is recommended here also that judicious use of grain cooling techniques to achieve a net enhancement of insecticidal efficacy in such treatments. Even for those insecticides which show a positive correlation between temperature and toxicity to insects the increase in chemical persistence, at lower temperature, outweighed the reduction in toxicity.

These several lines of research exemplify the possible refinements of established insect control procedures that are required for improved storage pest management. Such approaches are likely to prove more beneficial than attempts to devise complex packages of control measures, including as many as possible of the various available options, with the mistaken idea that IPM necessarily calls for such complexity. As was stated at the outset, the essence of IPM is the integration of cost-effective measures with management objectives and capabilities. With regard to this purpose, current efforts to develop computer packages ("Expert Systems") to guide management decisions are of interest. Systems with potential relevance to grain storage in the tropics include one, announced by the Australian Centre for

International Agricultural Research (ACIAR), which will provide advice to optimise the use of grain protectants, and another, from NRI, which addresses more generally the application of pest control in grain storage.

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CHAPTER 9

RODENT CONTROL

THE ECONOMIC IMPORTANCE OF RODENT PESTS

There are three major reasons why rats and mice are considered pests:

(a) They consume and damage human foods in the field and in stores. In addition they spoil it in stores by urine and droppings reducing the sales value.

(b) Through their gnawing and burrowing habit they destroy many articles (packaging, clothes and furniture) and structures (floors, buildings, bridges, etc.). By gnawing through electrical cables they can cause fires.

(c) They are responsible for transmitting diseases dangerous to man.

After harvest the crop attains its highest value, taking into account all the costs of producing it, processing, (packaging), storage and distribution prior to consumption. The actual value of the losses caused by rats vary by crop, variety, year, geographical location, pest species involved, length and method of storage and climate (Gratz 1990). The exact post-harvest losses are difficult to assess. A review can be found in Jackson (1977) and Meehan (1984). Some examples based on surveys are given below which indicate the huge financial losses that have been found and can generally be expected.

Surveys conducted in small warehouses in the Philippines indicated losses of 40 to 210 kg of grain in each (Rubio 1971, Agnon 1981 as cited in Benigno and Sanchez 1984); at the time this was equivalent to about US $ 80 for each unit. Interviewing farmers in Bangladesh on rodent damage inside houses provided an estimated loss equivalent to US $ 29.50 for a six month period (Bruggers 1983). This figure is supported by Mian *et al* (1984) who found that, on average, households were each infested by about 8 mice and 2 rats. At 10.5 million households the annual losses are estimated at US $ 620 million for the entire country in houses only. Higher estimates were found by Krishnamurthy *et al* (1967) in a similar study in India. In large grain stores the situation may be even worse. For example, Frantz (1977) estimated that each godown in Calcutta had, on average, a population of about 200 Bandicoot rats. At an estimated 50 gm one rat can destroy in one night appreciable losses will accumulate.

To these food losses, costs for cleaning produce, the losses due to damaged packaging (Meehan 1984) as well as structural damage have to be added. It is impossible to put an exact estimate on these losses, but it is obvious that the damage caused by rodents is enormous.

Diseases transmitted by rats to man pose a serious public health problem in tropical countries. Apart from causing human suffering, they are responsible for financial losses incurred through work-days lost and additional medical bills.

While this topic is not directly related to post-harvest problems, it bears relevance to post-harvest rodent control. As rodent pests in stores and households are controlled the rate of disease transmission will be reduced. Gratz (1988), Fiedler (1988) and Meehan (1984) have reviewed this aspect in detail.

Just as it is difficult to put exact figures on losses caused by rodent pests, it is not easy to estimate the exact benefits of rodent control. However it is apparent that rodent control is mostly if not always cost effective.

In the U.S.A. the annual loss to rodents is estimated at US $ 900 million (Clinton 1969 as quoted in Meehan 1984), while the annual cost of control is estimated at US $ 100 million (Brooks 1973 as quoted in Meehan 1984). According to Sumangil (1990) losses of rice in the Philippines were reduced from US $ 36 million to US $ 3.5 million with the advent of organised rat control programmes.

In Bangladesh two national strategic multi-media rodent control campaigns were organised and analysed in detail. Net profits were calculated at US $ 800,000 for each campaign, based on a single crop and season (Adhikarya and Posamentier 1987). Calculated benefits would be a multiple of this figure, if all crops could have been surveyed and the reduction in structural damage and human suffering could be quantified. Further field studies in the same country have shown clearly that losses can be reduced by 40-60% at farm level also (Posamentier 1989).

Dubock (1984) and Richards (1988) describe some examples of rodent control in urban and rural situations, including warehouses, in various Asian and Central American countries. The cost-benefit ratios ranged from 1:2 to 1:30. Hernandez and Drummond (1984) found that in Cuban warehouses the loss of 1% of the amount available to human consumption could be readily preventable by standard control techniques.

RODENT SPECIES OF POST-HARVEST IMPORTANCE

There are more than 4000 species of mammals, of which about 1700 are rodents (Anderson and Knox Jones 1967). Of the rodents the Family MURIDAE contains the most species, and of the genera the genus *Rattus*. However not all the 1700 rodent species are pests. About 150 species have been defined as a pest at some locality to some crop at some time or another, but only 20 could be termed important (Fall 1980). Very few species indeed are regularly described as pests in the literature. In connection with post-harvest losses, the number of species occurring in and around human habitation, drops to below ten.

Of these, three species are found throughout the world: the house mouse (*Mus musculus*), the house or roof rat (*Rattus rattus*) and the brown rat (*R. norvegicus*). The multimmate rat (*Praomys natalensis*) and the spiny mouse (*Acomys cahirinus*) are found in Africa; while the

pacific rat (*R. exulans*), the bandicoot rat (*Bandicota bengalensis*) and occasionally the striped squirrel (*Funambulus pennanti*) (Posamentier 1989) occur in Asia. Other species may enter buildings occasionally, but are of local importance only.

The brown rat, *Rattus norvegicus* (also known as grey, house, sewer, Norway, or wharf rat)

This species is cosmopolitan, but thought to have originated in Asia. It has spread gradually around the entire world during the last two centuries through international trade and human settlement (Meehan 1984). Its range is limited to coastal areas especially ports. In many Asian countries it is displaced by *B. bengalensis* (Deoras and Pradhan 1975), and it is probable that populations of *R. norvegicus* in these areas are replenished only by new arrivals from outside.

Many colour variations occur. In general it is brown-grey dorsally and light-grey ventrally, the tail is bi-coloured, and the feet are white. The head+body length is 180-250 mm and a fully grown adult may weigh up to 400 grams, although heavier individuals have been recorded (Niethammer 1981). The tail is shorter than the head+body length. The ears are thick, opaque, and short with fine hairs, while the snout (front of face) is characteristically blunt.

It is the most important species in Europe, because it lives in close proximity to man and has often been responsible for passing diseases on to man. Living in close social groups, it may be rated as the major post-harvest rodent pest in Europe.

The ship rat, *Rattus rattus* (also known as black, roof, fruit, rice field, or Alexandrine rat)

Also cosmopolitan and spread through international trade, this species originated in South East Asia (Meehan 1984). However, unlike *R. norvegicus*, the ship rat commonly lives well inland and has penetrated deep into continents.

There are many subspecies and forms of *R. rattus* and, because of this, it is difficult to give a definitive description of it. In the same country the coloration may range from almost black to red brown dorsally and dark grey to white ventrally. The head+body length is 150-220 mm and the fully grown adult weight is 150-250 grams (Niethammer 1981). The tail is longer than the head+body length. The ears are thin, translucent, relatively large and hairless, while the snout is comparatively pointed.

Although it has become fairly rare in Central and Northern Europe and Asia, *R. rattus* has become a field pest in many countries and, because of its good climbing ability, infests fruit orchards besides entering buildings. This species was responsible for carrying the fleas which spread the plague in the Middle Ages. For more detailed information on the biology of one of the subspecies, *R. rattus mindanensis*, see Sumangil (1990).

The Pacific rat, *Rattus exulans* (also known as the Polynesian rat)

This is a relatively small species. It is coloured grey-brown dorsally and light grey ventrally. The head+body length is 110-130 mm, and a fully grown adult may weigh up to 45 grams. The tail is longer than the head+body length (Niethammer 1981).

It is common throughout the Pacific islands ranging westward to western Bangladesh (Poché 1980), and is found in agricultural fields and in villages. Due to its excellent climbing ability it is a common pest of coconut trees.

The house mouse, *Mus musculus*

This species is also cosmopolitan, having apparently originated in the steppes of Central Asia on the Iranian-Russian border (Schwartz and Schwartz 1943). It is now the most wide-spread mammal in the world (Meehan 1984).

There are many subspecies and colour variations are extreme: the fur dorsally is usually brown to brownish grey (although black and other colours occur), and grey ventrally. The head+body length is 70-110 mm, and a fully grown adult weighs 15-30 gm. The tail is about as long as the head+body length. The ears are quite large in relation to the rest of the body, while the feet are comparatively small and the snout pointed.

The house mouse is a good climber and lives in social groups. It can be a serious pest in agricultural fields and buildings, but has also been recorded in native or natural vegetation.

The Egyptian spiny mouse, *Acomys cahirinus*

This species ranges from Mauritania to Pakistan and is usually found in semi-desert, rocky country, dry woodland, thorn scrub and savannah (Greaves 1989). However it has become commensal in some places, replacing *M. musculus*, causing damage to stored grain and domestic premises.

The commensal form is nearly black with a grey belly. The head+body length is 60-120 mm, and the tail much shorter than this. Hairs on the back are stiff, and are the distinguishing feature of this species. While litter size may be small (2-5), a female may have up to 12 litters in one year.

Apparently this species has an unusual resistance to anticoagulant rodenticides. This means that control has to rely on strict sanitation practices and the use of acute rodenticides such as zinc phosphide.

The multimammate rat, *Praomys (Mastomys) natalensis*

This species is economically the most important rodent pest in Africa, and a true indigenous commensal (Fiedler 1988). In many areas it may be replaced by the much larger *R. rattus*.

The fur is soft, brownish on the back and greyish underneath. The head+body length is up to 150 mm, and the fully grown adult weight is 50-100 g. The tail, which is uniformly dark, is about the same length as the head+body.

Most distinctively, the female has up to 24 nipples on her belly (other rat species rarely have more than 10) and the reproductive potential is high, particularly since this species lives in large social groups. Consequently, very large population explosions occur from time to time, causing huge losses.

The lesser bandicoot rat, *Bandicota bengalensis*

This is a common species in Asia, which ranges from Pakistan eastwards and, according to some reports, has reached Indonesia. Otherwise it does not seem to have left the mainland continent of Asia. It seems to be replacing *R. rattus* and *R. norvegicus* in India (Prakash 1975) and probably other Asian mainland countries also.

The fur is dark or (rarely) pale brown dorsally, occasionally blackish, and light to dark grey ventrally. The head+body length is around 250 mm, and the uniformly dark tail is shorter than the head+body length.

In addition to consuming or spoiling much stored produce, the lesser bandicoot rat is a very active burrower and is responsible for much structural damage to the storage buildings as well. It is also a very good swimmer able to live in deep water rice fields, where it can cause much damage to the crop. In Bangladesh and Myanmar (India) it is the most important rodent pest in both urban and rural areas. It is certainly also important in other Asian countries.

B. bengalensis is very aggressive even against individuals of the same species (Posamentier 1989); consequently, the large burrow systems made by these rats are normally occupied by only one adult each.

This species is very susceptible to most rodenticides (Brooks *et al* 1980, Poché *et al* 1979), although findings by Greaves (1985) indicate that some individuals seem very tolerant to some rodenticides. However in practical field trials in Bangladesh no problems were encountered with zinc phosphide or coumatetralyl (Posamentier 1989).

Notes on the Biology, Behaviour, and Habits of Rodent Pests relevant to their control.

(i) Reproduction

Although most rodents live for only about one year they are prolific breeders, multiplying rapidly under most favourable conditions. A female rat may have up to to five litters in her lifetime, *R. norvegicus* and *R. rattus* averaging 7 or 8 young in each litter. The multimammate rat can have up to 20 young in a litter, the average being about 11. A female bandicoot rat may share a burrow with a weaned litter, have a litter suckling and be pregnant all at the same time. The house mouse can have a new litter every four weeks (Meehan 1984).

(ii) Senses

Rodents have well developed senses of smell and touch, but poorly developed eyesight. They have excellent light sensitivity but poor acuity and are colour blind (Meehan 1984). This allows poison baits to be coloured, for safety reasons, without modifying their acceptability by the target species (assuming that the colouring agent does not have an adverse taste or odour).

They possess a good sense of hearing including frequencies in the ultrasonic range up to 100 Khz. This has led to the development of ultrasonic deterrent devices, of variable effectiveness.

(iii) Physical capabilities

The following facts need to be remembered when it is intended to rat-proof a building.

R. rattus, *R. exulans*, and the house mice are very good climbers, *R. norvegicus* less so and the bandicoot rats almost not at all. However all are able to use very small openings for their size or move up cracks and pipes to gain access to buildings. They are also good swimmers and readily take to the water. They are also good jumpers: *R. norvegicus* can jump vertically 77 cm and horizontally more than 120 cm, house mice can jump to a height of 24 cm (Meehan 1984).

The burrowing activity of rodents (especially the bandicoot rats, *R. norvegicus* and the multimammate rat) is a particular nuisance to store owners in tropical countries. Floors subside, easing the entry of other individuals, providing hiding places, causing a loss of stored produce and even leading to a partial collapse of buildings.

Rodents make burrows to breed in, for storing large amounts of food, and for protection against predation and extreme climatic conditions. In the case of bandicoot rats these burrow systems may be 100 cm deep and very extensive. Additional small 'escape burrows' are made by some species to minimise travelling to food and water.

R. rattus and house mice do not always make burrows but construct well hidden nests on the ground, in trees, or the upper parts of buildings.

Rodents derive their name from their gnawing behaviour (Latin: *rodere* = gnaw). Their incisor teeth grow continuously and need to be used, otherwise they will grow back into the cheek disabling proper feeding. The ability to gnaw through even soft metals is not only a nuisance but can also be hazardous, as mentioned in the opening paragraph of this Chapter.

(iv) Eating Habits

Rodent pest species are omnivorous, an additional reason why they are successful pests. In spite of this there may be some preferences in the field if a choice is available. Overall, rats and mice in the wild will take a balanced diet.

The quantity of food taken may also vary. Under laboratory conditions, rodents have been

observed to consume about 10% of their body weight per day (Chitty 1954, Meehan 1984, Spillet, 1968, Brooks *et al* 1981, Posamentier and Alam 1981). Enclosure studies indicate that under near field conditions the amount consumed or destroyed is about five times the amount eaten in the laboratory (Haque *et al* 1980), although the proportion actually consumed is uncertain. What is certain, however, is that the actual losses caused are a multiple of their dietary requirements.

Many workers have studied food preferences in attempts to find the 'perfect' bait. The results of these studies are very variable depending on genetics, learning ('food imprinting'), weather and other complicating factors. A review of the subject can be found in Meehan (1984) and Posamentier (1989). In terms of bait acceptance the most important variable is to lay the bait at a time when little food is available. In buildings this means making food as inaccessible as possible, which will be discussed later.

Most rats return to a fixed place of feeding. House mice on the other hand are haphazard, inquisitive feeders (Crowcroft 1966).

(v) Activity

Most activity takes place during the hours of darkness, which is also when they do most of their feeding. There are two peaks of activity, the major peak occurring just after sunset and a minor peak just before sunrise. This has been observed for *M. musculus* (Dewsbury 1980), *R. rattus* (Barnett *et al* 1975), *R. norvegicus* (Calhoun 1962) and *B. bengalensis* (Parrack 1966). When hungry, or under crowded conditions, they may also be active during daylight hours.

(vi) New Object Reaction and Bait Shyness

It is probably their ability to rapidly adapt their behaviour to new or changing situations, above all else, that has caused some rodent species to become major pests. This is most apparent in their reaction to 'new objects' placed in their environment by man.

R. norvegicus is naturally very suspicious and tends to avoid any object that is new to it. It may take several days before an individual will enter a trap or take bait. Even then, if the new object appears to be food, only a small amount is taken. If the food contains an acute poison causing symptoms after a short while, rats may not touch the bait again. This is commonly called **bait shyness**.

R. rattus behaves similarly but not to the same extent, while *M. musculus* tends to explore rather than avoid new objects.

The New Object Reaction wears off in time, but has to be taken into account when a rodent control programme is planned.

(vii) Movement

Many rodent pests are characteristically mobile and able to disperse rapidly. This allows them to move quickly into and take advantage of new areas with favourable conditions (Fiedler 1988, Meehan 1984). However once individuals have established a territory or home range, they will not move very far, as long as conditions remain favourable.

It is often believed that rodent pests invade areas from several kilometres away. This is not exactly true. If large numbers of rodents suddenly appear in an area, it is probably because environmental conditions have become favourable for them, and indigenous populations are able to increase at several places in the area at about the same time. This then gives the impression that the animals are on the move. It should be realised that for such a small ground living animal like a rat it is far too risky to move long distances because of predation and exhaustion.

Nevertheless it is known that bandicoot rats, and others, will move from surrounding fields into villages at harvest time, that is when fields suddenly no longer provide enough food (Posamentier 1989). In built up areas containing food stores *B. bengalensis* moves within an area 30 to 146 meters in diameter (Spillet 1968, Chakraborty 1975, Frantz 1984), depending on the location of the warehouses, when they are emptied, structural conditions and the availability of water.

Under experimental conditions and in certain environments *R. norvegicus* will move about three kilometres in one night (Meehan 1984). It is therefore not surprising that disinfested areas are quickly invaded by new animals from neighbouring areas or buildings. Increasing the area in which a rodent control programme is to be carried out will therefore help to reduce the rate of reinvasion.

(viii) Habitat

Rodents prefer buildings with good cover in surrounding areas; where vegetation reaches right up to the walls of the building, which ideally (for them) should have soft floors, broken brickwork and the like, and be untidy (Figure 9.1). Under such conditions control, particularly with rodenticides, is virtually impossible.

Competition

Animals compete for food and shelter. Such competition may be either inter- or intra-specific; that is between different species or among members of the same species.

For example it has been shown that *B. bengalensis*, *M. musculus* and *R. rattus* compete with one another for space; the bandicoot being the dominant species, and the house mouse the least competitive. In the context of control this means that if *B. bengalensis* is successfully eliminated from a store, *R. rattus* may move in. If *R. rattus* is then removed, *M. musculus* will move in. This situation needs to be considered when devising a control strategy, because the control techniques for these different species vary.

Several species live in loose or tight social groups (i.e. *R. rattus* and *R. norvegicus*) with a fairly fixed hierarchy. More dominant animals will have first access to food and shelter. In a control programme this means that the more dominant animals are removed first, because they are first to feed on the poisoned bait. The parts of the population lower in the hierarchy will be controlled with the second or subsequent bait applications. The technique of 'pulsed baiting' is based on this behaviour and is discussed later in this Chapter.

Figure 9.1. Open structures enable rats to enter buildings, while refuse close-by attracts them.

Indicators of the presence of Rodents

There are several ways by which rodents may signal their presence. The most easily noticed are damage and burrows. In stores footprints may be noted in dusty places and, of course, rodents will leave their droppings scattered about. Often the species can be identified by the size and shape of droppings.

Less obvious are the 'smears' found in places regularly visited by rats. They are caused by rats brushing their bodies against objects or when they slide around rafters and corners. Smears are indicators of heavy usage and infestation, and good places for laying down tracking powders[1].

[1] Tracking powders or contact dusts are placed on runways and other places frequented hy rats, for example near burrow entrances. Their primary function is for the detection of rodents, which leave their footprints in the dust when they walk over it. They can also contribute towards the control of the house mouse (see the section on Contact Dusts).

However these signs are normally apparent only after a substantial population has become well established, when the point in time for economical control has already passed. The acute observer should try to find the more subtle signs of rats just passing through to investigate the store. This can be done by searching for foot prints in fine sand or tracking powder placed at strategic points. Areas around and outside the store should also be checked frequently for the presence of rodents.

CONTROL OF RODENT PESTS

Principles of Control

Before the various techniques, methods or strategies of controlling or managing rodents are described the general principles involved need to be discussed. An understanding of these principles by all those involved will assist in devising specific control strategies for a given situation. It will also help when explaining the need for certain activities to the staff actually executing the control work.

In tropical countries rodents pose a continuous problem because of the climatic conditions, uninterrupted food supply and relatively open structures. Therefore the control of rodent pests should be approached as a **management** problem much more so than a simple and single poisoning action. For a control strategy to be effective staff responsible need to be trained and informed, their activities must be co-ordinated, responsibilities confirmed, inputs and equipment readily available and the entire action must be planned.

Control strategies should aim at preventing losses and thus require a pro-active rather than the more normal reactive approach (Colvin 1990) (Figure 9.2). Once a large population of rodents has established itself in a store considerable losses, that cannot be retrieved, have already occurred and subsequent control action is expensive. It should stressed that information from different sources should be incorporated into a control or management strategy and not just the techniques.

There are many more techniques and methods of controlling rats than are described here. Those given here have been selected as being the most practical for use in tropical countries. Meehan (1984) provides a comprehensive description of techniques and a complete list of available rodenticides.

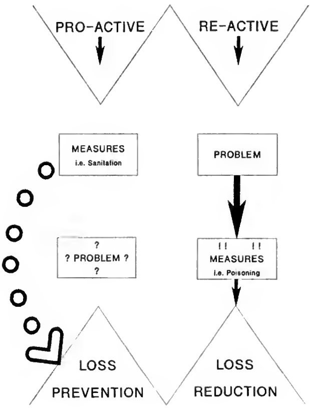
(i) Monitoring

An important element of any rodent programme is monitoring. Usually it means surveillance for the presence of rodents. However it should also mean looking for features in the environment which would encourage rodents to migrate into it. Monitoring should be organised formally and regularly; that is, specific staff should be made responsible for it and report regularly, maybe once a week to a superior on the situation. The report should include the following aspects:

- dates monitored;
- number, types and positions of signs of rats;

- condition of the building (broken pipes, walls etc., state of produce, tidiness or cleanliness);
- conditions immediately outside the building with respect to potential infestation points;
- qualitative reports by others;
- dates of baiting;
- number of bait stations used and positions;
- amount of bait and labour used;
- recommendations for improvement, such as repairs to structures, or further action required.

Figure 9.2. The philosophy behind any management strategy should be the **prevention** of problems.



Control of a rodent infestation is rarely completely successful; but if it is, it is usually only for a very short period. Therefore there is a need for continuous monitoring even after a successful control campaign regardless of the techniques and bait used.

For more ideas on monitoring techniques see Kaulkeinen (1984).

(ii) Co-operation

If an area is made rat-free due to good management and/or effective control measures, rats from near-by areas will migrate into it. It is therefore more efficient if control campaigns are conducted in several adjacent areas simultaneously. In the case of a village all households should be motivated and organised to control rats at the same time. While control in one household will still benefit the owner, benefits increase as the number of participating neighbours increases.

In the case of stores, large and small, surrounding areas including other stores should also be disinfested. This means that all the store keepers or managers involved should co-ordinate and synchronise their rodent control activities for maximum effect.

Preventive Measures

The maxim: 'Prevention is better than Cure' is just as true for rodents as it is for other pests and diseases. Therefore the prime objective of any rodent control campaign should be to create environmental conditions which will discourage or prevent the pests from re-entering an area after its rodent population has been removed by one means or another.

(i) Sanitation

Rodents require food and shelter. Therefore it is most important to reduce the availability of these two key factors, which should be central in devising any kind of strategy. In the case of buildings the most effective method of rodent prevention is the improvement of **hygiene** or **sanitation** in and around them. Primarily this means sweeping the store and keeping both it and the surrounding area neat and tidy, i.e. free from any objects such as empty containers, idle equipment or discarded building materials, which could provide cover or nesting places for rodents. It also means removing food scraps left over from feeding pets or domestic stock (i.e. poultry farms) at the end of the day's work.

Observations have shown over and again that these simple actions, even in the tropics, are the most effective preventative measures that can be taken.

In a tidy store any infestation will be noticed at a very early stage, making other control measures far more effective. With reduced access to food and no places to hide, rats will not become established, that is live and breed, inside a building. Regular disturbance is something rats and mice avoid.

Control procedures should take the life history and behaviour of species present into account (Colvin 1990). Rats avoid clear spaces. Therefore by keeping a strip of two or more metres around a building clear of vegetation will reduce the chance of rats entering the building.

This should be augmented by keeping a strip of about one metre on the inside from the wall totally clear and swept. Branches overhanging the building should be lopped off to prevent climbing species to enter from above.

The above suggestions are enough to eliminate serious problems with rats and mice in buildings, even in stores where large quantities of food items are stored. Rats feel uneasy if their 'paths' and 'markings' are removed or cleaned daily by sweeping. They will not feel secure enough to remain in a building and damage packaging in their search for food. If they do, the damage is minimal and immediately noticeable.

(ii) Proofing

Since it is not practical to remove all food from stores and households, it is necessary to restrict access by rats. This is accomplished by **proofing** buildings or keeping food in rat-proof containers.

When rodent-proofing a building only materials which they cannot gnaw through should be used. Also, it should be remembered that some rodent species are good climbers and jumpers, and most can squeeze through surprisingly small holes and cracks (young mice need no more than a 0.5 cm wide crack to gain access).

Hard metal strips should be fitted to the bottom edges of all wooden doors and their frames, and vulnerable windows should be protected with tight wire netting screens in hard metal frames. Steel rat guards fitted to drainpipes and other attachments to the building should be at least one metre above ground level. Door hinges and similar fittings should be so placed or protected that rats cannot use them for climbing.

Floors and walls should be kept in good repair. New holes dug by rats should be filled in immediately, with cement reinforced with pieces of crumpled chicken wire. If cement is not immediately available a temporary seal can be effected with tightly packed earth between the wire mesh. The important point is that repairs should be carried out as soon as the damage is noticed, which should be within a few hours of it being done if the building is inspected daily.

Although rats are active mainly after dark, they will move about during day as well when there is no human activity. Therefore doors of stores should stay tightly shut during the day as well, when the store is not in use.

If the building itself cannot be made rat proof, then foods and other valuables should be kept in earthenware containers or metal drums with good lids.

Jenson (1965) provides further detailed information on rodent proofing.

(iii) Natural Prevention (Predation)

Normally predation will not keep rats and mice at economic population levels. One exception is the keeping of cats. Cats do not directly control rats and mice by feeding on them. It is their presence, which keeps most rats and mice away. A survey conducted in

a Myanmar village has clearly shown that households with cats had no rats while those without cats in the same village were visited by rats.

Examples where predation may have an effect on field rodents and its limitations are described by Prakash (1990) and Wood (1984).

While work done in Australia on controlling house mice with a nematode has shown promise (Singleton and Redhead 1990), there is no practical parasitic control method for rats and mice available at present.

Mechanical Control

Mechanical rodent control as a rule is not very practical. It is cumbersome, labour intensive, and often not very efficient. Mechanical techniques are more appropriate in households, and can be used if the owner has no access to poisons or is averse to their application

The method most commonly used in buildings is trapping. Often local traps are available and in some cultures people are very good at using them. They should be placed where rats move regularly. If placed along a wall, the trap should be perpendicular to it and the treadle with the bait should face the wall.

Sticky or glue traps are another way of catching rats and mice (Prakash 1990, Meehan 1984). They are boards made of wood, hard- or cardboard covered with very sticky material. There are different types of glue available and they should be checked for suitability (stickiness, and usability in humid or dusty conditions) before large quantities are ordered. The boards are placed in the same way as traps, and normally there is no need for bait to attract rats. These traps should be checked daily, but are not regarded as very 'humane'.

Flushing rodents out of their burrows, with smoke or by flooding them with water, can be very effective and suitable in some situations. Ultrasonic devices are mentioned regularly, particularly by manufacturers of these devices, as a good repellent of rats and mice in buildings. However there is no scientific evidence of their effectiveness. It appears that rats become habituated to the sound or stay in 'sound shadows'. The subject is discussed by Meehan (1984).

Chemical Control

In large stores, particularly if situated in the city, it may be necessary to complement hygienic practices with chemical control. Because acute poisons invariably cause bait shyness, especially if applied over longer periods, it is strongly recommended that only anticoagulant rodenticides are used in buildings. Therefore acute rodenticides will not be discussed here.

It should be remembered that rats living in and around buildings are particularly suspicious of new objects, such as bait, bait stations and traps. Therefore it may take some time before

these are accepted by rats[2]. For this reason it is important that once these objects are placed they are **not touched or removed** again. If the bait or trap has not been touched after, say, a week rats are probably not nearby and it should be moved to another location. However chemical control is only useful in connection with strict hygienic practices.

As a rule operators should be supplied only with ready-to-use rodenticide baits. Firstly, mixing can be dangerous to the operator. Secondly, a wrong concentration can lead to bait shyness if too high, or to sub-lethal dosing if too low. Normally ready-to-use baits do not increase costs substantially.

ALL rodenticides can also harm other animals including man. Therefore great caution should be observed at all times when they are used.

(i) Anticoagulant Rodenticides

Anticoagulant rodenticides interfere with the blood clotting mechanism of the body - the animal gradually dies because of loss of blood through external and internal wounds, that is haemorrhage. Very small internal wounds (breaking of small capillaries) are constantly caused by normal movements. The rat feels almost nothing, it simply feels more and more tired and eventually dies. Therefore bait shyness with anticoagulants is unusual even with higher concentrations of active ingredient.

Resistance to some anticoagulants has been observed in industrialised countries, where they have been used very extensively over long periods. So far, resistance has been of no serious consequence in tropical countries, particularly in view of the fact that new compounds (e.g. difenacoum, brodifacoum, bromadiolone) are now available in most countries. The antidote to anticoagulant rodenticides is Vitamin K.

Multiple Dose Anticoagulant Rodenticides

Multiple dose anticagulant rodenticides, such as **coumachlor** or **coumatetralyl**, need to be

[2] There is a considerable amount of literature on the acceptance of different bait formulations by rats. For a simple overview on the topic of food choice see Posamentier (1989). Normally commercial formulations are acceptable, and the local operator may experiment himself. If loose bait is used it should be applied in containers or on plates inside buildings. For easy application bait blocks can be used (Smythe and Khan, 1980). Normally bait blocks with or without wax are used outside buildings. Their advantage is that they can be nailed on structures, easily placed on beams and inside burrows. No implements including bait stations are required. Another advantage is that they can be carried away by without spillage. Bandicoot rats take small blocks (about 5 gm) inside burrows. Some authors claim they are not accepted well in comparison to other formulations (Meehan 1984).

Liquid formulations may be useful in very dry situations. Continuous water supply containers for chickens can also be used for offering such formulations to rats. However, there should be no other source of water within 100 metres - not even a slowly dripping tap. Many rats realise that the liquid contains a foreign substance and will not drink it in the presence of other water sources. Here also the need for regular monitoring cannot be stressed too much. The liquid may evaporate to such an extent that the concentrated poison will be rejected by rats. Therefore it is recommended that small but frequently replenished quantities be used instead.

available at all times because rats have to feed on the bait several times over a period of up to seven days (depending on the species) before death is caused.

The poison bait should be placed inside bait-stations[3]. To save resources each bait station should contain 50 to 100 gm of bait at all times. Bait availability should be checked each morning and bait taken by rats or which has become mouldy should be replaced. The quantity of bait used depends on the level of infestation and should be adapted to local conditions; and the number of bait stations necessary depends on the size of the building. As a rule of thumb a station should be placed every five to ten meters along the wall. Additional bait stations should be located in positions where rats are likely to enter a building, along obvious rat runways, or in places where rats may hide. The distance between bait-stations depends on the species involved: house mice, for example, normally have a smaller feeding range than rats. However an operator will quickly learn how and where to place bait-stations, if the situation is regularly monitored and the operator is not changed[4].

If no more bait is taken and it appears that no more rats are present, baiting can be discontinued. However surveillance should continue and baiting must be re-started at the first signs of rats.

Single Dose Anticoagulant Rodenticides

Single dose anticoagulant rodenticides, such as **brodifacoum, flocoumafen or bromadiolone** act in the same way as described above but rats normally have to feed on the poisoned bait once only (1.5-2.0 g for rats in the case of the most potent compounds such as brodifacoum). In some situations and for some species it appears that more than a single feed is necessary (see Meehan 1984). Overall though these anticoagulants are by far the most poisonous to rats and very useful to practical rodent control.

If loose bait is available the use of bait-stations is recommended. These prevent spillage and spoilage. If blocks are used they can be laid down at regular intervals and in places frequented by rats, but should not be accessible to other animals or children.

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[3] Bait-stations are protected baiting points. That is bait is put inside a tube or box or underneath some cover. The idea is to protect the bait against moisture from below, reduce access by non-target animals, and provide rats with seclusion inducing them to feed.

Very often though bait-stations are not used, because they are bulky to handle and add costs. Whether bait stations are used or not has to be decided by the operator. If access by other people to a store is very limited, covered bait-stations may not be required. However to facilitate monitoring of bait, particularly loose bait, taken by rats it is advised to used marked baiting points, for example by placing bait on small plates or sheets.

[4] The rate of application in terms of quantity and position depends on many factors. People working in stores know the places frequented by rats; walls, edges, openings etc., and these are the logical positions for baiting points. If climbing species are present, bait should also be placed in elevated positions. It is suggested to start with about 50 grams of single-dose anticoagulant rodenticide bait at each point. Depending on the monitoring results this amount is increased or decreased (but see the section on pulsed baiting). The operator will quickly gain sufficient experience, if he stays on the job, to place bait most efficiently.

(iii) Pulsed Baiting

The technique of **pulsed baiting** was introduced with the new single-dose anticoagulants, such as bromadiolone and brodifacoum (Dubock 1979, 1984). This contrasts with **saturation baiting**, in which bait is available to rats continuously over long periods until the population has declined to near zero. Pulse baiting is not necessarily more effective, but it is certainly cheaper, because the amount of labour and the quantity of bait required is much lower than in saturation baiting.

As mentioned earlier, death is delayed by three or more days after ingestion (depending on the species of rat and the type of rodenticide). This means that rats will continue to feed on bait even though they have received a lethal dose, which would be a waste of bait. In addition in some species (e.g. *R. norvegicus*), animals of lower hierarchal ranking cannot feed until 'higher' animals are removed from the population.

This behavioural characteristic is exploited by baiting in pulses. Poisoned bait is laid for 1-3 days (depending on the rodenticide) and discontinued for about a week, allowing the first batch of animals to die and thus be removed from the population. The next baiting pulse will remove another batch of rats. Normally three baiting pulses are sufficient to remove almost the entire population. The intensity of baiting periods (pulses) depends on the rat population in and around the building and the rate of immigration from neighbouring areas. In spite of the above the intervals between and number of pulses has to be decided each time based on the results of monitoring.

The positive experience with the use of pulsed baiting in different countries and crops is summarised in Dubock (1984).

(iv) Perimeter Baiting

The idea of perimeter baiting is to place bait in a circle around and outside the immediate area of interest and hopefully prevent rats from immigrating. However it is very difficult to give exact guidelines on the diameter of the circle, the distance between baiting points and the quantity of bait to use. The idea has its merits and an operator should experiment with this technique; for example, by placing baiting points between the store and places through which rodents might reasonably be expected to immigrate.

(v) Fumigation

Individual rodents may be killed incidentally during the fumigation of grains and buildings for the control of insects (see Chapter 8). This section deals specifically with fumigation for rodent control.

The control of rodents by fumigation can be very effective, but it may be expensive and dangerous. It should be remembered though that the gas must have access to burrows, if these are present in the building. That is the burrows should be open and the fumigant used must be heavier than air.

If the species concerned makes burrows which are easy to spot (e.g. *R. norvegicus*, *B.*

bengalensis or *P. natalensis*), they can be fumigated directly. The simplest method is to use a powder which releases hydrogen cyanide, or aluminium (magnesium) phosphide tablets which release phosphine when placed into the burrows. The gases are generated when the powder or tablets come into contact with moisture in the soil. Alternatively, methyl bromide gas may be pumped into the burrow system.

As soon as the fumigant has been applied all burrows must be closed, by filling the entrance holes with earth. However, fumigants cannot be used in loose or sandy soils as too much gas escapes, and the treatment may not be effective. Occasionally, rats have been known to block tunnels and prevent complete distribution of the gas, so that some individuals survive.

It is important therefore, always to check for reopened burrows or other signs of survival a few days after the prescribed fumigation period.

Fumigatlon gases used for rodent control are also dangerous to man and other animals. Therefore, strict safety precautions must be observed (Meehan 1984). Only trained and properly qualified operators should be employed to use fumigants. They should be seen to be observing the following basic principles of fumigation:

1. two operators must always be present at a fumigation;
2. suitable respirators must be worn;
3. operators should stand upwind when gassing;
4. fumigants should not be used in strong winds or when it is raining;
5. fumigants must not be used near buildings inhabited by man or animals as open burrows may be inside; and
6. operators should know about first aid and have appropriate first aid equipment with them.

Contact dusts

Contact dusts are dusts containing rodenticide which are placed on runways and other places frequented by the house mouse, for example near burrow entrances. Such dusts, while serving also as tracking powders (see earlier), are favoured in the control of house mice which, because of their erratic feeding behaviour, are not easily controlled by baiting. The dust is picked up on the fur and feet and, since mice groom themselves often and regularly, it is automatically ingested.

However care must be taken when using such dusts, as they may easily contaminate stored products like grains and may be undetectable.

Safety

Rodenticides, whether chronic (i.e. anticoagulants) or acute, are poisons and should be treated as such and at all times. Some may be more toxic to humans or non-target animals than others, some non-targets may be less affected by certain rodenticides than others.

Nevertheless, it is important that safety procedures are rigidly enforced wherever they are used. Meehan (1984) discusses the toxicity of various rodenticides in some detail.

Standard safety precautions when handling poisons include:

- wearing protective clothing during operations;
- not eating, drinking or smoking during operations;
- not breathing in dust during operations (wear dust mask);
- keeping baits out of reach of others, especially children and domestic animals;
- thoroughly washing the skin, clothing and equipment after operations.

Unwanted poisoning

Much has been written about the potential danger to non-targets of feeding on bait (primary poisoning) or animals feeding on poisoned rats (secondary poisoning). For a short overview the reader is referred to Kaukeinen (1984), Godfrey (1984), Hoppe and Krambias (1984) and Hegdal *et al* (1984).

It is difficult to assess the exact effect under practical conditions. Unwanted poisoning reported by large scale operations or through accidents, usually involve domestic animals. To date no significant effects on non-rodent wildlife have been associated with the use of conventional anticoagulants (Kaukeinen 1982). The danger of unwanted poisoning can be virtually eliminated in buildings if some simple rules are adhered to:

- bait should be laid so that no other animals, including man, can have no access to it; in buildings this should be fairly simple;

- the amount of bait laid out should be adapted to the anticipated population of rats, that is as little as necessary and placed in small quantities per station;

- application should be late in the afternoon, just before rats become active and as birds retire; in stores this is not so important;

- bait should be removed entirely after a control programme is terminated;

- dead rats, if found, should be buried or burnt; and

- rodenticides should be under lock and key, and empty containers should be disposed of properly.

Stray dogs and cats (and crows and vultures in some countries) may be at risk through feeding on dying or dead rats (secondary poisoning). Normally these animals, because of their size, would need to feed on several rats before they would be affected and more to receive a lethal dose. The chance is very low with most anticoagulants and even with zinc phosphide, because most of the poison is broken down in the stomach. Nevertheless,

operators should be aware of these potential dangers at all times.

DESIGNING CONTROL PROGRAMMES

There is no step by step advice or specific strategy one could propose to cover all situations. The strategy needs to be developed by a knowledgeable person familiar with the situation concerned. Even then, it will be necessary to test different procedures. The discussion below will attempt to provide some general ideas, which would assist in developing such a strategy and will stress some points to clear misconceptions.

Even today people still talk about rat free towns or stores. This may be possible in theory or in some special situations. However it is expensive and impractical (Drummond 1969) and certainly unrealistic in the tropics (Wood and Chan 1974).

When designing a strategy one should also decide on and differentiate between the temporary clearing of a heavily rat infested store and the long term **prevention** of rat infestations. The latter should be aimed at; because it is cheaper, more rewarding and more professional in the long run. This points to all the measures called for under hygiene and sanitation. Modern rodenticides are good but, at least in buildings, hygienic practices are better.

In this respect the key factors are **organisation and regular finance** (Sanei *et al* 1984). This means that planning, execution and monitoring of all activities are of paramount importance (Meehan 1984, Drummond 1981). They include the following points:

- collection of all relevant information leading to a control strategy and plan of action relevant to the situation at hand;

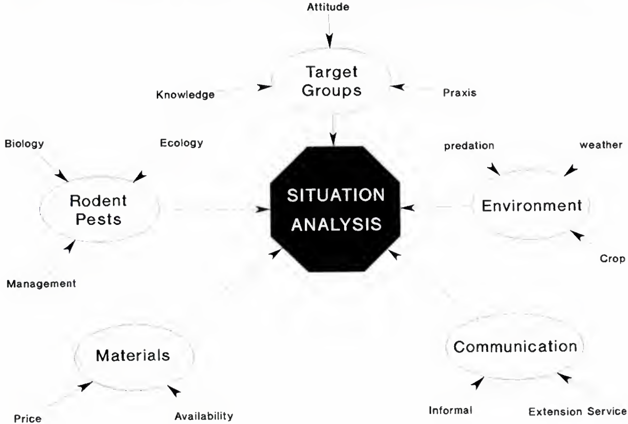
- communication on and co-ordination of the programme with other interested parties; and

- appreciation of the problem by all involved.

The information obtained from surveys and other sources will flow into the situation analysis and control strategy, that is: who should be involved, where are the points of infestation, which repairs are necessary, what costs can be expected, and what are the potential losses. It is considered justifiable to spend an amount equivalent to the value of about 10% of the potential losses on rodent control.

The level of co-ordination and co-operation required depends on the situation. In a village it may mean motivating and informing all households. A store situated in an isolated rural location would require the involvement of the owners of the fields surrounding the store. If the store is situated in a city or port, other storekeepers or the council may need to be involved. As mentioned earlier, the larger the area involved in a rodent control programme, the more effective it will be.

Figure 9.3. A well performed situation analysis is the first step in developing an effective and suitable management strategy.



One person on the premises should have a fair knowledge of rodents and their control. Although training may not be essential, it helps in improving efficiency. Most people, particularly in tropical countries, have learned to live with rodents. Therefore, it is necessary to create a general awareness of the problems and the benefits (Dorrance 1984), and preferably involve as many people as possible in the control programme. The importance of making a specific person **responsible** for rodent control (Becker 1981) is often overlooked. It is necessary to be able to report to a responsible person, since this will ensure **continuity** of activities. Often after an intensive control campaign, and the reduction of the rat population, interest wanes and with it all associated activities until the next heavy infestation occurs (cf. Hoque and Saxena 1988).

Making a person responsible for rodent control may be the first and most worthwhile step a warehouse manager can make towards reducing his rat problems efficiently.

The following more specific guidelines may serve as a starting point in the design of a plan of action.

Management

Efficient rodent control can only be executed when the necessary framework for it is set. The points below would be the **responsibility** of the **manager** of a warehouse or warehouses or the chief extensionist for a village.

1. Installing a person responsible (rodent control officer) for rodent control including a job description;

2. setting up a monitoring and reporting system;

3. providing a labour force or designating people to assist the rodent control officer in his duties;

4. making all necessary materials and equipment available when needed;

5. organise and execute short information or training courses for staff or households;

6. creating a budget for rodent control;

7. co-ordinating and/or co-operating with other relevant groups and people; and

8. supporting the rodent control officer in the execution of his duties.

Monitoring

It is important to emphasise that monitoring must be performed **regularly** and promptly reported on. As far as possible it should include costings of potential losses (from damage surveys), costs of control and potential benefits. Reports must include recommendations for

future actions, and a **plan for action** based on the results of monitoring. It is suggested that reports are submitted at least once a month. This will aid management in providing budgets and motivate all people involved.

Technical Aspects

The procedures and techniques listed below are considered to be most effective, and should appear in the plan of action. They need to be adapted to local requirements, and could therefore include techniques not mentioned in the list. The person responsible for each action, and the time/date when it has to be executed, must be named in the plan of action.

1. Sanitation must remain in the forefront of any rodent control, inside and outside the building, including:

    - removal of vegetation and rubbish outside close to the building;

    - tidying the store inside removing items that do not belong there and keeping strips near walls clear;

    - regular cleaning by sweeping and removing all food scraps (i.e. from feeding pets or animal food in poultry sheds) in the late afternoon;

    - checking incoming and outgoing produce for infestation;

    - occasionally clearing the entire store of all produce and cleaning it out thoroughly.

2. Proofing the building: including regular, even if simple, repairs and other improvements.

3. Chemical control should be seen as an adjunct to sanitation and be in line with the following recommendations:

    - use of new generation single dose anticoagulants;

    - operators and workmen should handle only ready to use bait formulations;

    - pulsed baiting is suggested as the first technique to be tried;

    - perimeter baiting should be considered;

    - application techniques should be practised constantly and improved as monitoring results dictate; and

    - all safety measures should be observed.

The effectiveness of rodent control arrangements depends upon the people responsible for their implementation being aware of the problems involved, their motivation and their interest in achieving success. The tools required are: (a) regular monitoring, (b) well trained operators and (c) access to labour and materials when they are needed. It is fair to claim that in rodent control the problem are mostly concerned with people and not the rats. Hence the reduced stress on control techniques in this Chapter.

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ANNEX 1
(Reference Chapter 1)

APPLICATION OF COST-BENEFIT ANALYSIS TO STORAGE PROJECTS

Introduction

In this publication, it is not possible to provide a full description of the techniques of Cost-Benefit Analysis (CBA), for which purpose the reader is referred to suitable texts such as those by Gittinger (1982), Irwin (1978) or the Overseas Development Administration (1988).

CBA is used for choosing between different options, by comparing the net benefits of each option, that is the total benefits minus the total costs. To simplify calculations, only the differences in costs and benefits need to be compared. Indeed in many cases one is comparing projects which provide identical services and therefore benefits; in such cases it is only necessary to compare the difference in the costs between the options compared.

Before carrying out a CBA, it must first be decided whether the analysis is to be *economic*, i.e. from the point of view of the country as a whole, or *financial*, i.e. from the point of view of the individual operator, company or organisation which makes the investment. The economic analysis tells one whether the project is worth supporting as a matter of public policy; the financial analysis whether the project is sufficiently profitable to interest the operator(s) concerned. According to which type of analysis one is conducting different approaches are needed in the valuation of costs and benefits. Often one must analyse the project from both viewpoints.

In this Annex it will be shown how CBA was applied by the Natural Resources Institute in two cases, involving respectively large-scale and small-scale storage.

Application of CBA in a large-scale storage project; bag versus bulk handling in Pakistan

The reader is referred to Chapter 1 for the background and main findings of the study, which was carried out by Coulter (1991).

In this case an *economic analysis* was required, to determine whether public sector food handling agencies were justified in adopting bulk handling and storage. In order to measure the costs and benefits of different options the following factors had to be accounted for:

(i) **Capital costs**, including the cost of land, buildings, plant and machinery, and working capital with which to operate them. The decision to invest in a new technology involves committing capital and time which might otherwise have been used for other purposes. The income foregone is assigned a value, called the *opportunity cost*. The opportunity cost is valued at the return which the capital would have earned if invested in the most profitable alternative use.

While this concept of opportunity cost is attractive, in practice it can be difficult to quantify. Often economists use the cost of borrowing, and in economic analyses this is the cost to the

country of obtaining international loans at commercial rates, net of expected inflation in the currency concerned(inflation is not a cost in *real* economic terms). Rates ranging from 5% to 12% have been applied in different studies. Conventionally major aid donors often use a 10% rate, and this practice was followed in the Pakistan case.

In order to compare technologies with different useful lives the fall in the value of the capital investment over time (its depreciation) must be accounted for. It is also necessary to account for variation in the capacity utilization of different technologies.

There are different ways of allowing for capital costs in CBA, but one of the most useful and that adopted in the Pakistan case was to express the capital costs in terms of the *annualised cost* of using the technology, given its initial cost and its useful life. This is done using an *annuity factor*, which takes account of both depreciation and the opportunity cost of capital tied up in the investment. It can be obtained from a standard table of annuity factors (e.g. Gittinger, 1982 p.435). It allows for a direct comparison of technologies with different initial costs and different life spans. The following example shows how this can be done.

A miller has an alternative of investing (a) £100,000 in plant and equipment with useful life of ten years, or (b) £120,000 in plant lasting 15 years. He expects to mill 20,000 tonnes of wheat per annum. His cost of capital is 15%.

The annuity factor for a ten year investment is 5.019, and for a fifteen year investment 5.847.

The annualised cost of:

investment (a) is £100,000/5.019 = £19,924
investment (b) is £120,000/5.847 = £20,523

The cost per tonne of wheat milled:

for investment (a) = £19,924/20,000 = £1.00
for investment (b) = £20,523/20,000 = £1.03

Conclusion: The annualised cost of investment (b) is marginally higher.

(ii) **Other fixed costs.** Fixed costs are costs which do not vary with the level of utilization, and will be incurred each year even if the technology is not used. Capital costs are likely to be the most important fixed cost, and others include maintenance, supervision, security, rent, information systems, managerial overheads and so on. In practice it can be difficult to decide whether a particular cost, such as store management, is a fixed or a variable cost. Some costs, such as electricity from a national grid, can include both a fixed and a variable charge.

For large millers or Government corporations, who are able to invest in major storage structures and equipment, fixed costs are likely to be high. In the Pakistan case, it was found that capital costs and maintenance were the two most important cost factors to be

considered when comparing long-term storage options. Indeed they were much more important than the cost of bags and labour (both of which are saved by mechanical handling), and the prospective reduction in storage losses.

(iii) **Losses**. Great care is needed in quantifying losses, avoiding *heroic* and unreliable estimates of the kind noted in Chapter 1. It is also important to compare like with like, e.g. an improved bulk system with an improved bag system, not an improved bulk system with a poorly managed bag system which exists at present. In some countries estimates of current levels of losses are available from survey data, but often there are no such data, in which case it may be advisable to test the CBA with different values, as described below under *sensitivity analysis*. When carrying out economic analyses, quantitative loss can be valued as follows: for a country which is a net importer of the grain concerned, it is the cost of restoring the loss through imports; in an exporting country, it is the net export revenue foregone. Qualitative losses can be valued as the difference between the realisable value of the stock in its original and deteriorated form. In financial analyses, the loss value is simply the net financial loss to the operator.

(iv) **Other variable costs**. Variable costs vary with usage of the technology. They depend on the amount of grain in store, the length of time of storage, the amount of grain which is handled or milled, and include losses (which we have discussed above), bags, handling labour, storage insecticide, fuel, electricity to operate equipment, and *queuing costs*. Care is needed in estimating the cost of bags in a particular operation, as they are generally reused, and when deteriorated, can be sold on to other users e.g. for carrying potatoes. The following approach is suggested:

Bag costing £0.18, with resale value £0.06
Number of times handled before resale = 20
Cost per time handled =£0.12/20 = £0.006
Handling required in storage operation - fill in field and load on truck, unload and stack at middleman's premises, unstack and load on truck, unload and stack at storage centre, unstack and loan on truck, unload and empty at mill.
Total times handled = 6 times
Cost of sack to operation = 6 x £0.006 = £0.036

A cost may also be attributed to the capital tied up in the bags, as in the case of a capital asset.

Queuing costs are the costs incurred by truckers who have to wait for their grain to be received and unloaded at a grain store, depot or mill. In comparing bag and bulk options they may be important, because bag handling systems may be characterised by long queues of trucks waiting for labour to unload them; mechanical handling may speed up handling and turn-around time, and allow the trucker or shipper to use his assets more economically.

In the Pakistan study, this saving was put forward as a reason for converting long-term storage facilities to bulk handling. In practice it was found that most of the queuing which

characterised the existing bag-handling system was due to the official inadequate labour rates and systems for labour contracting. It was estimated that the queues could be cleared by doubling the rates. To allow for this, the study costed handling labour used in bag handling options at a *shadow rate* twice the value of rates actually paid. The practical impact of this change on overall grain handling and storage costs was minimal, indicating that the appropriate solution to the queuing problem was indeed better contracting systems and labour rates.

These different costs were estimated and added up for each scenario and each option considered, on a per tonne basis. The results obtained for one scenario, the building of brand new long-term storage facilities, are shown in Chapter 1, Table 1.1. The table allows a simple comparison of the cost per tonne for each option considered. Notwithstanding possible errors in some of the assumptions used in this analysis, the table illustrates the power of CBA in comparing alternatives.

Application of CBA to storage by small farmers

The reader is referred to Chapter 1 for the background and main findings of this study, which was carried out by Boxall and Bickersteth (1991). The objective of the exercise was to assess whether recommended changes in storage practices were profitable for farmers, that is to say the analysis was of a *financial*, not an *economic* kind.

A number of assumptions were made concerning capital costs, the opportunity cost of capital, labour costs, and the losses suffered under different technologies. It was assumed that all stores would be used to maximum capacity throughout their useful lives.

Decisions on an appropriate opportunity cost of capital are most difficult in this kind of analysis, as one has to ask: *What is the opportunity cost of capital to the farmer?* Is it (a) the cost of borrowing on informal markets, which may be as much as 10% per month? Is it (b) the cost of bank credit at between 27% and 33% per annum (less inflation which is not a true cost of capital)? Or should (c) a somewhat higher rate than this be used to provide a risk premium which the farmer needs to induce him to invest **his own equity capital** in the venture?

Faced with such decisions, economists generally use simple rules of thumb, and in this case the analyst used two alternative discount rates 10% and 20%. Net of inflation the range between these two rates reflect a compromise between criteria (b) and (c). However given the general scarcity of capital in rural areas of Africa the 20% rate is probably closer to the farmer's true opportunity cost of capital.

The results of the analysis are shown in Chapter 1 (Table 1.2) as a *break even point*, which shows, under each option, the price to which maize must rise for the farmer's investment to pay for itself.

Some other approaches to CBA

Both of the above cases involved comparing the costs of two technologies for carrying out the same activity. Revenue (or benefits) was not computed because it is the same for all options. In other cases one has to appraise the case for a new activity, involving consideration not only of the costs but also the revenue or benefits derived from the activity. Where grain is being stored longer than before the opportunity cost of capital tied up in this grain must be computed.

Often the benefits of increased storage of grain will not accrue to the operating company or marketing board concerned but will accrue to the country as a whole through increased production of crops in response to better producer prices. Here the increased output may be valued as benefits, while the cost of fertiliser, labour etc. to produce this extra output may be counted as costs.

In such cases the results are often appraised using a simple ratio of benefits to costs, the *cost-benefit ratio*, or by computing the *pay-back period*, the *net present value (NPV)* or the *internal rate of return (IRR)*. *Break even analysis* can be used in other ways than that shown above, for example by measuring the amount of time a product has to remain in store for a particular technology to become profitable. One advantage of break even analysis is that it can be used in situations where there is doubt, or where a choice needs to be made, about the value of one particular variable.

Pitfalls and Limitations of CBA

(i) False assumptions in the calculation of costs and benefits

We have already mentioned the danger of inaccurate loss estimates. Another common way in which benefits can be overestimated is by assuming higher or more stable capacity utilization than in fact occurs. For example, the capacity utilization of a dryer will depend on the amount of rain at harvest. If sun drying is feasible it is generally more cost-effective than using mechanical dryers, since no capital investment is required, although the labour requirements may be higher. In the case of new stores, capacity utilization depends on the size of harvest and market price at harvest, and may vary widely from year to year.

(ii) Data requirements

Cost-benefit analysis is quite demanding in terms of the data requirements. Even where the capital and variable costs of different options are relatively easy to obtain, it can be difficult to arrive at accurate estimates of the value of losses, or to find relevant price data for rural areas.

If estimates of losses are available, they are often expressed in terms which are difficult to convert to market values. Losses are commonly expressed in terms of percentage weight loss, but the market value will also depend on losses in quality, and may depend on where the weight loss has occurred. Weight loss in the germ of grain kept for seed may mean a total loss if germination can no longer occur, while weight loss in the husk of grains which are subsequently milled may have little effect on the income obtained.

Even where data on past losses or prices are available these are not always a good guide to future events. This leads us to the third problem with CBA.

(iii) Dealing with uncertainty

There are a number of ways of accounting for the uncertainty of future benefits using CBA. One of the simplest is to do a *sensitivity analysis*. If a particular piece of data is uncertain, then the net benefits are calculated using different estimates for the unknown value and results are compared. For example, if losses under different systems are not known then different values for losses are used, to cover the range of likely possibilities. If there is little difference in the net benefits derived then the accuracy of the particular piece of data is not very important for selecting the preferred technology. But if small changes in the estimate lead to large changes in the net benefits then it is advisable to try to improve on the estimates before any recommendations concerning the technology are made.

Another method of dealing with uncertainty about future events is to use a *pay-off matrix*. In this case the possibility of a range of future events is accounted for explicitly, and the outcomes of using the technology under each of the possible scenarios is calculated. It is then up to the potential user to assess the likelihood of any particular event occurring, and therefore, the risk involved in using a particular technology. If an estimate can be made of the probability of different events then the 'expected outcome' of each technology can be calculated.

An example of a pay-off matrix, using hypothetical figures for net benefits per ton of grain, using different drying technologies, is given below:

	Wet Harvest	Dry Harvest
Sun dry	\$300	\$1500
Mechanical dryer	\$600	\$ 600

In this example, a miller investing in a mechanical dryer would gain in a wet harvest but lose in a dry harvest, compared with the sun drying alternative, and assuming the same level of utilization in wet and dry years. The dryer is less profitable than sun drying in a dry year because of the higher capital costs. The lower net income from sun drying in a wet harvest results from higher losses or lower sale price for wetter grain.

In order to decide whether to invest in the dryer it is necessary to know how many years, over the life of the dryer, are likely to be wet years. If the dryer lasts 10 years, and the probability of a wet harvest is 30% in any one year then the calculation would be as follows:

$$(600 \text{ X } 0.3)+(600 \text{ X } 0.7) = \$600$$

and for sun drying: $(300 \text{ X } 0.3) + (1500 \text{ X } 0.7) = \$1,140$

Pay off matrices are particularly good for tailoring decision making, or recommendations regarding different technologies, to individual circumstances. Each individual can assess the probabilities of different events, and the level of risk they are prepared to take. For example, the miller might have a minimum income requirement of at least $500 dollars in any one year in order to repay debts. In this case a technology which offers high pay off in good years, but gives an income of less than $500 in bad years will be rejected.

(iv) Failure to predict farmer behaviour

It is commonly found that technologies which do well on CBA are nevertheless not taken up by farmers.

An important reason is that the costs and benefits used in the calculation often do not reflect the actual costs incurred by the user, or the benefits which are available to the user (Compton, 1992). For example, the cost of local materials may be undervalued. Even where wood, mud and other materials are not marketed, they may be in short supply, or there may be local systems of ownership and distribution which impose scarcity or some kind of cost on the user. Families may value unpaid labour at less than the opportunity cost assumed by the analyst.

Benefits in terms of technical improvements will only be enjoyed as benefits if they are reflected in market prices. For example, increased milling yields or reduced mycotoxin levels from dryers will be of no benefit to farmers until these factors are reflected in the prices they receive.

Incentives to adopt new technologies also depend on who will bear the costs and who will enjoy the benefits. For example, if women are required to shell maize for storage, while men gain from the increased income, there may be disagreements within the farm household as to the desirability of the new storage methods (Compton 1992).

Clearly, a good understanding of the local economy, farming system, storage practices and division of labour are required if the results of CBA are to be useful in predicting the uptake of different technologies.

Another problem with CBA is that it often doesn't reflect the farmer's reasoning process. Small farmers make choices about farm investments with incomplete knowledge of future events. They are often 'risk-averse' and therefore choose options with steady average returns even when these are low compared with the potential gain from risky alternatives. The risks involved in adopting the same technology may be very different for a small farmer for whom grain crops provide the main source of income than for a wealthy farmer, who has other sources of income and can afford to incur losses on grain cultivation from time to time.

Potential users generally have a very wide range of criteria for selecting different technologies which cannot be adequately represented in a CBA, including such factors as the taste of the consumed product, the avoidance of neighbours' jealousy, or theft, or the ease of removing grain from a store. However due account of these phenomena can be taken by carrying out a proper demand assessment, using the approaches outlined earlier.

ANNEX 1 REFERENCES

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ANNEX 2
(Reference Chapter 5)

ORGANIZATIONS INVOLVED IN RESEARCH ON BIOMASS RESIDUE COMBUSTION

ASEAN Sub Committee on Non-Conventional Energy Research (SCNCER), P O Box 51, Ratburanan, Bangkok, Thailand.

Asian Institute of Technology, P O Box 2754, Bangkok, Thailand.

Biomass Technology Group, University of Twente, P O Box 217, 7500 A E Enschede, The Netherlands.

Energy Information Service, Commonmwealth Scientific and Industrial Research Organization, P O Box 89, East Melbourne, Victoria 3002, Australia.

Regional Office for Asia and the Pacific, FAO, Phra Atit Road, Bangkok 10200, Thailand.

Indian Institute of Technology, Hauz Khas, New Delhi 110 016, India.

Indonesian Institute of Research and Development and Agro-Based Industries, Jln Ir H Juanda 5-9, Bogor, Indonesia.

International Rice Research Institute, P O Box 933, Los Baños, Philippines.

Natural Resources Institute, Central Avenue, Chatham Maritime, Kent ME4 4TB, United Kingdom.

Regional Energy Resources Information Centre (RERIC), P O Box 2754, Bangkok 10501, Thailand.

ANNEX 3

(Reference Chapter 4)

EXAMPLE OF CALCULATING THE COSTS OF OPERATING PROCESSING MACHINERY

This example is given only to indicate how the calculations are carried out. It cannot be transposed as such to concrete case studies. Assuming that:

a farmers'organization has purchased a rice thresher through a local agricultural credit office;

they plan to work on their own farms, but also possibly for farmers out of the organization;

they need to determine the operating cost of the machine.

(i) Assumptions

Purchase conditions in Fcfa

- Purchase price including the price of the machine, commissioning costs, cost of the loan, etc.		1,600,000
- Personal contribution		320,000
- Bank loan:	* amount	1,280,000
	* annual rate of interest	15%
	* maturity	5 years
	* constant annuities	381,844
	TOTAL INTEREST	629,220

The machine has not been insured and no shelter has been specially built for it.

Technical Specifications

- Diesel engine horsepower	8hp
- Fuel cost	210 Fcfa/l
- Lubricant mean cost	800 Fcfa/l
- Output per hour	500kg
- 2 operators The other workers required for feeding the machine, bagging and winnowing operations are paid by the customer.	3,000 Fcfa
- Repair costs over the useful life, i.e. 0.5 as coefficient	800,000 Fcfa

- Useful life	5 years
- Working time per day For a labour presence of 8 hours (maintenance and transport of the machine from stook to stook)	6 hours
- Paddy mean yield	5t per ha
- Sundries: machine transport, bags, etc... Because custom services are paid a percentage of the crop, marketing costs are included.	2,000 Fcfa/day

(ii) Annual performances

- Work time	* in days	110 per year
	* in hours	660 per year
- Fuel consumption: 0.12l/hp/h x 8 hp x 660 hr/year		634l per year

(iii) Annual costs

Fixed costs

The interest rate of the bank is applied to the personal contribution (i.e. 320,000 Fcfa actually paid by the purchaser), the remaining sum being borrowed.

When refunding a loan with constant annuities, interest amounts decrease each year. To make the calculation easier, 1/5th of interest is used here as annual financial charges.

As the annual use (hr) is lower than the ratio of the useful life in hours (Hr) to years of depreciation (N), amortization is considered as a fixed cost(A): A = Purchase price/N

- Interest on capital: 320,000 x 15 / 2	24,000 Fcfa
- Amortization: 1,600,000 / 5	320,000 Fcfa
- Financial charges: 630,000 / 5	126,000 Fcfa
TOTAL FIXED COSTS	470,000 Fcfa

Variable costs

- Fuels: 634 L x 210 Fcfa/L	133,140 Fcfa
- Lubricants: 634 L x 2,5 x 800 Fcfa/L/100	12,700 Fcfa

- Repairs: $\dfrac{1{,}600{,}000 \times 0{,}7 \times 660 \text{ hr/year} \times 5 \text{ years}}{3500 \text{ hr}}$	105,600 Fcfa
- Labour cost: 3,000 Fcfa/d x 110 d/year	330,000 Fcfa
- Sundries: 2,000 Fcfa/d x 110 d/year	220,000 Fcfa
TOTAL VARIABLE COSTS	801,440 Fcfa

That is a gross total of 1,271,440 Fcfa per year, or 1,896 Fcfa per hour. For an efficiency of 5000kg per ha, the operating cost can therefore be estimated at 18,960 Fcfa per ha.

ANNEX 4
(Reference Chapter 6)

FUMIGABLE WAREHOUSES

Conventional and traditional warehouses have frequently been fumigated, either by sealing gaps in the structure (Webley and Harris, 1979)[1] or by enveloping the entire building under gas-proof sheeting. However, such operations are never simple and are often fraught with difficulties. Bulk grain storage facilities are usually constructed with fumigation in mind and, unless they are structurally faulty, are sufficiently gas-tight for this purpose.

The fumigable warehouse briefly described here was developed in the sahelian zone of west Africa (Hayward, 1981), and is intended for long-term storage of reserve stocks of grain. Much of what is written in Chapter 6 about the location, design and determination of size of standard warehouses applies equally to fumigable warehouses. Only the differences relating to sealing of the warehouses are highlighted in this Annex.

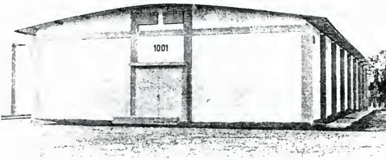
Walls: Constructed of hollow concrete blocks, these are rendered smooth with cement plaster and then covered on the inside with a special plastic paint.

Roof: The spaces between the aluminium roof sheets and the girders along the tops of the side walls are plugged with shaped wood pieces soaked with wood preservative and bitumen. A liberal coating of bitumen is then painted on and around the plugs.

Ventilators: These are fitted externally with tight fitting flanged metal covers, which can be locked and sealed with gas-proof sealing tape.

Doors: The hinged metal doors are tight-fitting, and have flanges overlapping the frame set in the wall so that the gap all round is not greater than 2 mm. When the doors are closed for a fumigation this gap is closed completely with gas-proof sealing tape.

Figure A4.1. Fumigable warehouse in Senegal.



[1] References quoted in this Annex may be found at the end of Chapter 6.

ANNEX 5

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